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16. ABSTRACT

The Campbell Red Lake Mines Gold Smelter at Balmerton, Ontario, Canada, has developed and implemented a successful control strategy for arsenic emissions from a nonferrous smelting operation. The Red Lake smelter uses cyclones and a hot electrostatic precipitator to recover metal values from roaster dusts with subsequent air quenching to condense (or desublime) arsenic trioxide which is recovered in a low-temperature baghouse. This report presents the results of the test program conducted at the Red Lake gold smelter during the period September 18-28, 1978. The overall efficiency for the control of particulate emissions using a combination of a hot electrostatic precipitator, an air quench in a mixer-cooler, and a cold baghouse exceeded 99.9%. Collection of particulate arsenic in the baghouse was greater than 99.95%; however, overall arsenic collection efficiency in the baghouse was slightly less due to passage of As_2O_3 vapors. Total arsenic emissions from the system were only 11 mg/dscm (6.8×10^{-7} lb/dscf or 0.20 Kg/hr (0.44 lb/hr).

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EVALUATION OF TECHNOLOGY FOR CONTROL OF ARSENIC EMISSIONS AT THE CAMPBELL RED LAKE GOLD SMELTER

by

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Grant No. R 804955

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report presents the results of a field test and evaluation of a highly effective system employed on a nonferrous metals application for the control of arsenic trioxide air emissions generated in the roasting of arsenic sulfide bearing gold ores. The Nonferrous Metals and Minerals Branch of the Energy Pollution Control Division should be contacted for further information.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Since arsenic is a significant component of ores processed in the nonferrous metals industries, it is of interest to characterize and evaluate control strategies which have demonstrated the potential for lowering the emission rates of arsenic and other hazardous effluents from smelter operations. The Campbell Red Lake Mines Gold Smelter at Balmerton, Ontario, Canada, has developed and implemented a successful control strategy for arsenic emissions from a nonferrous smelting operation. The Red Lake smelter uses cyclones and a hot electrostatic precipitator to recover metal values from roaster dusts with subsequent air quenching to condense (or desublime) arsenic trioxide which is recovered in a low-temperature baghouse. A test program was conducted at Red Lake to characterize the control systems and to evaluate the potential for transferring the technology to nonferrous smelting operations in the United States.

This report presents the results of the test program conducted at the Red Lake gold smelter during the period September 18-28, 1978. The overall efficiency for the control of particulate emissions using a combination of a hot electrostatic precipitator, an air quench in a mixer-cooler, and a cold baghouse exceeded 99.9%. Collection of particulate arsenic in the baghouse was greater than 99.95%; however, overall arsenic collection efficiency in the baghouse was slightly less due to passage of As_2O_3 vapors. Total arsenic emissions from the system were only 11 mg/dscm (6.8×10^{-7} lb/dscf or 0.20 Kg/hr (0.44 lb/hr).

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The gas sampling and analysis were conducted by Radian Corporation, Austin, Texas under the direction of Dr. John C. Terry.

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SECTION 1

INTRODUCTION

The Campbell Red Lake Mines operation at Balmerton, Ontario, Canada has developed and implemented a successful control strategy for arsenic emissions from a nonferrous smelter. In their process, a gold-bearing arsenopyrite ore is roasted in a two-stage fluid-bed roaster to eliminate arsenic, antimony, and sulfur. The hot roaster calcines are recovered in a series of cyclones followed by a hot electrostatic precipitator, with the precipitator and cyclone catches being returned to the gold recovery system. Hot gases from the precipitator are quenched with ambient air to condense (or desublime) arsenic trioxide which is then collected in cold bag filters before the particulate-free gas is exhausted to the atmosphere. Overall collection efficiency of the system exceeds 99.9% for all particulate and 99.8% for arsenic trioxide. As_2O_3 emissions from the system are almost exclusively in the gaseous state and amount to only about eleven milligrams per dry standard cubic meter of exhaust gas.

Since arsenic is a significant component of many ores processed in this country by the nonferrous metals industry, the characterization and evaluation of control strategies which have demonstrated capabilites for reducing the emission rates of arsenic and other hazardous emissions from smelters is of interest. The test program at Red Lake was conducted to evaluate the performance of their "hot ESP/cold baghouse" system and to assess the potential for transferring the technology to nonferrous smelting operations in the United States.

SECTION 2

CONCLUSIONS

Field tests conducted at the Campbell Red Lake Mines gold smelter at Balmerton, Ontario, Canada have demonstrated and confirmed that the use of a hot electrostatic precipitator (operated above the dewpoint of As_2O_3) followed by quenching with ambient air to condense (or desublime) As_2O_3 with subsequent collection of condensed particulate in a baghouse operated at a low temperature (at which the As_2O_3 vapor pressure is very low) is potentially viable technology for control of arsenic emissions from nonferrous smelters.

Operation of the hot electrostatic precipitator at temperatures above the dewpoint of As_2O_3 provides a mechanism for efficient recovery of metal values for recycle to the smelting operation without significant condensation of arsenic. Subsequent quench cooling with ambient air effectively condenses the As_2O_3 to fine particulate which can be collected in a baghouse with low emissions of arsenic if the cooler-baghouse system is at a low temperature (circa 100-110°C).

The particulate collection efficiency of the hot ESP in use at Red Lake was about 98.3%; the particulate collection efficiency of the cold baghouse was greater than 99.9%; and the overall collection efficiency for arsenic was about 99.8%, with the major part of the emission being as volatile As_2O_3. The arsenic emission was a direct function of the vapor pressure of As_2O_3 at the baghouse outlet.

Based on the tests conducted at Red Lake, it was concluded that the system is a potential candidate for technology transfer to other nonferrous smelters that process arsenious ores. However, the technology is probably not applicable to smelting processes where the smelter gases are either utilized for production of sulfuric acid or water scrubbed before being released to the atmosphere.

A preliminary evaluation of potential technology transfer, to a particular smelter stream can be made with only a limited amount of data including the arsenic input and distribution within a system, the gas flows and temperatures in existing (or proposed) control devices, the subsequent treatment and disposition of the gas, and the vapor pressure of As_2O_3.

SECTION 3

PROCESS DESCRIPTION

A simplified flowsheet of the overall operation of the Campbell Red Lake Mines Limited installation at Balmerton, Ontario, Canada, is shown in Figure 1. Ore from an underground mine is subjected to crushing, grinding, ball milling, flotation, and tabling to obtain three cuts for further processing. The first cut (tabling overflow) is amalgamated directly for recovery of gold, the second (flotation tails and underflow) is relatively low in arsenic and sulfur and can be treated by cyanidation to liberate the gold, but the third cut requires roasting to produce a leachable calcine and eliminate arsenic, antimony, and sulfur which interfere with cyanidation. Two-stage fluid-bed roasting effectively removes the arsenic, antimony, and sulfur from the concentrate. The calcines from the roasters, cyclones, and hot electrostatic precipitator can then be treated by cyanidation to recover the gold. The hot gaseous effluent from the electrostatic precipitator is quenched with cold air to condense As_2O_3 which is recovered in a cold baghouse.

A more detailed flow diagram of the roasting, gas cleaning, and arsenic recovery system at Campbell Red Lake Mines is shown in Figure 2. The concentrate (nominally 9% As, 18% S, 23% Fe-design basis) is fed to the first fluid-bed roaster as a slurry containing about 80% solids. The design capacity of the system is 2500 Kg/hr (2.7 tons/hr)(dry basis). Most of the primary roaster air is fed to the first roaster which is operated at about 540-565°C (1000-1050°F) where most of the As, Sb, and S are oxidized and volatilized. The overflow and underflow from the first roaster are further treated in the second fluid-bed roaster at at about 500-525°C (925-975°F) to assure maximum elimination of As, Sb, and S from the calcines. The gases from the second roaster are fed through 2 parallel sets of 3-stage cyclones operated at about 400°C (750°F), and the calcine catch from the cyclones is combined with the roaster bed underflow for return to a cyanidation circuit for recovery of gold.

The gases from the two banks of cyclones are combined and diluted with air to reduce the gas temperature to 370°C (700°F) before being fed to the electrostatic precipitator which consists of 2 units in parallel with 2 chambers in each unit. The precipitator is double-walled, and electrically-heated air is

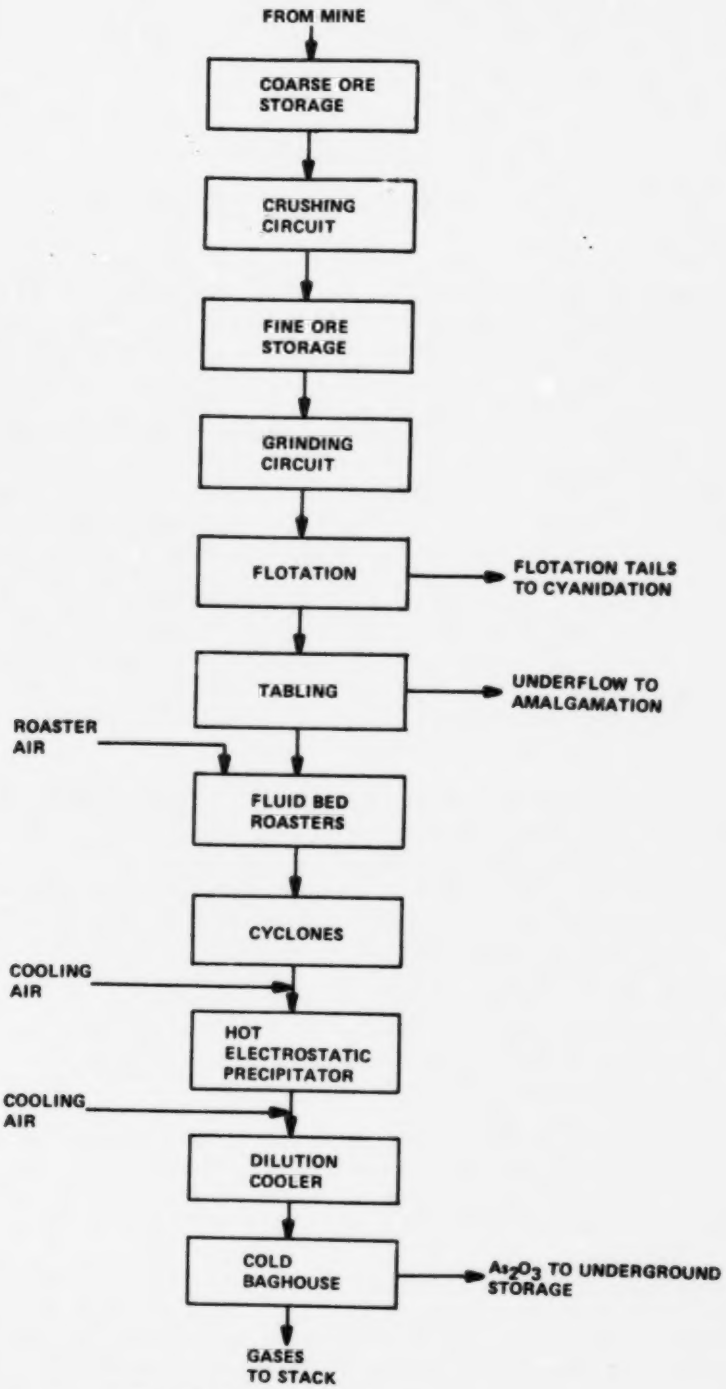

Figure 1. Simplified flow diagram.

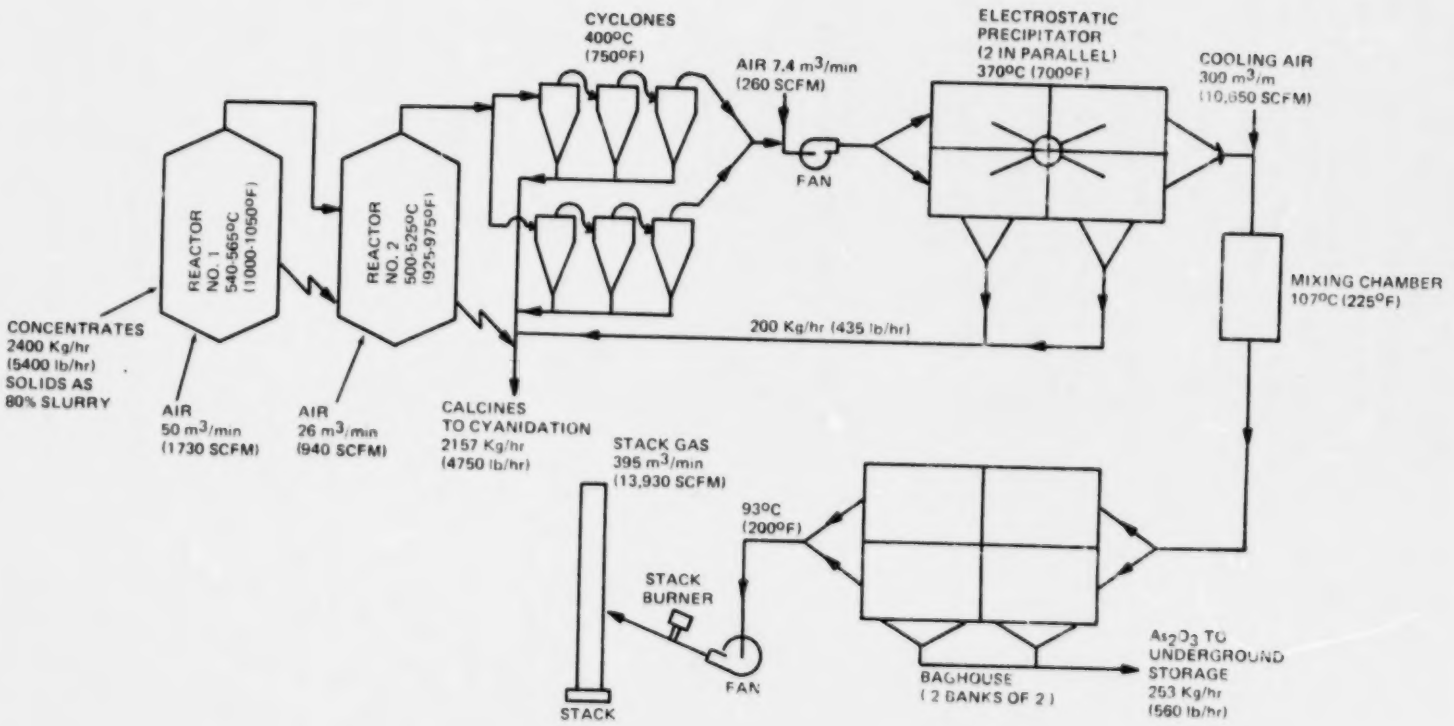

Figure 2. Roasting and Gas Cleaning Process (Design Flows).

circulated through the outer shell to maintain the wall temperature above the condensation point of As_2O_3. As will be shown by the data in this report, very little sublimed arsenic (primarily As_2O_3) is condensed in the precipitator and only particulate arsenic (perhaps as As_2S_2 carryover, a combined complex, or as As_2O_5) is removed in the ESP with the other entrained particulate from the hot cyclones. The hoppers from the electrostatic precipitator are emptied periodically, and the catch is combined with the roaster and cyclone calcines for return to the gold recovery system.

The hot precipitator off-gases are then mixed with ambient air to reduce the temperature to about 107°C (225°F) to condense the sublimed arsenic (As_2O_3). This particulate is caught in a 4-chamber baghouse before the gases are sent to a double-walled stack. The arsenic trioxide dust from the baghouse is removed periodically and conveyed to underground storage. The burner shown in Figure 2 was provided to reheat the gases to obtain plume rise; however, the burner has not been needed in normal operation.

Descriptive parameters for the precipitator are given in Table 1. The precipitator is a double-walled unit, and electrically-heated air is circulated in the shell to maintain temperature and avoid wall condensation. One transformer rectifier powers all four chambers of the precipitator. During the test period, the roaster system was operated at around 90% of design capacity so the actual SCA during the test was about 60 $m^2/(m^3/sec)$ or about 300 $ft^2/1000$ acfm.

Parameters for the baghouse are shown in Table 2. The baghouse is insulated, and the stack is also a double-walled unit to avoid wall condensation.

A key feature of the Red Lake System is the mixing chamber used for cooling the hot gases from the precipitator to condense or desublime the As_2O_3. A simplified diagram of this mixer-cooler is shown in Figure 3. Ambient air is fed into the center of the mixer, and the hot gases from the precipitator are fed tangentially to create a swirling mixing action. Ideally, condensation (or desublimation) of As_2O_3 occurs only at the juncture of the hot and cold gas streams. Wall condensation is avoided by keeping the hot gases on the outer periphery and by heat tracing and insulating the walls. Air flow to the mixer-cooler is controlled to maintain a baghouse temperature below 110°C (225°F).

The overall roasting and gas treatment system at Red Lake was designed by Hatch Associates Ltd., Toronto, Canada[1,2], the hot-side precipitator was designed by Joy Manufacturing Co. (Canada) Ltd., and the baghouse was designed by Wheelabrator Corporation of Canada Ltd.

TABLE 1. ELECTROSTATIC PRECIPITATOR DESCRIPTIVE PARAMETERS

Item	Metric	English
Collection electrode area (4 chambers-2 sets parallel)	187.3m^2	2016 ft^2
No. of fields per chamber	1	1
Collection electrode spacing	25.4 cm	10 in.
Collection electrode dimensions	1.83 x 1.83m	6 x 6 ft
Corona electrode dimensions (round wire)	0.268 cm	0.1055 in.
Wire spacing	22.86 cm	9 in.
Number of gas passages (per chamber)	7	7
Gas passage length	1.83 m	6 ft
Volume flow rate (design)	3.44 m^3/sec	7300 acfm
Design temperature	371°C	700°F
Design efficiency	98%	98%
Design specific collection area (SCA)	54.37 $m^2/(m^3/sec$	276.2 ft^2/ 1000 acfm
Measured efficiency (particulate)	98.3%	98.3%
Arsenic capture (total)	15%	15%

TABLE 2. BAGHOUSE DESCRIPTIVE PARAMETERS

No. of compartments	4
No. of bags (per compartment)	230 (10 rows of 23)
Bag material	Draylon T (acrylic)
Bag diameter	10.16 cm (4 in.)
Bag length	2.44 m (8 ft)
Air-to-cloth ratio (actual)	9.36 x 10^{-3} $(m^3/sec)/m^2$ (1.84 $ft^3/min/ft^2$)
Measured efficiency (particulate)	99.9+%
Arsenic capture (total)	99.8%

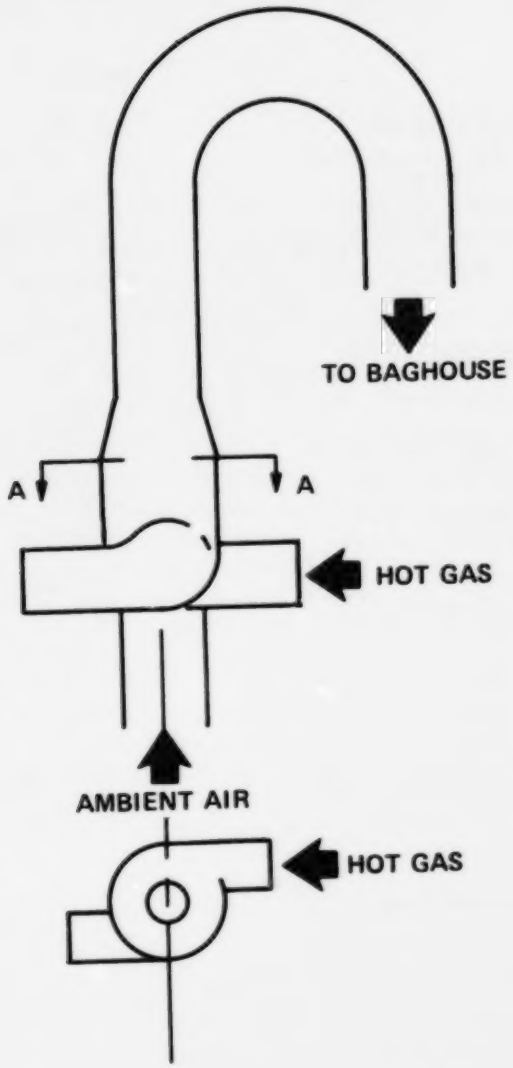

Figure 3. Gas mixer-cooler. *

* U.S. Patent 4,126,425 and Canadian Patent 993,368 assigned to Hatch Associates Ltd., Toronto, Canada.

SECTION 4

SAMPLING PROGRAM

During the period of September 18-28, 1978, personnel from Southern Research Institute and Radian Corporation carried out a test program in the Campbell Red Lake Mines Ltd. gold smelter at Balmerton, Ontario, Canada.

Radian Corporation personnel operated an integral sampling system designed to obtain particulate and gas samples for elemental analysis, and a gas sampling system for determining concentrations of sulfur oxides.

Southern Research Institute personnel operated cascade impactors for determination of the particle size distribution of the particulate in each gas stream, and a total particulate sampling system for determination of total particulate loading in each stream. SRI personnel also monitored the in situ resistivity of the particulate entering the baghouse (for possible modeling of a precipitator which could replace the baghouse).

The primary purpose of the test program was to evaluate the performance of the gas treatment system which consists of a hot electrostatic precipitator for recovery of metal values, a mixer-cooler for condensation (desublimation) of As_2O_3 and Sb_2O_3, and a cold baghouse for removal of fine condensation particulate. A simplified sketch indicating sampling points is shown in Figure 4.

Sample Point 1 at the precipitator inlet was under positive pressure, and some difficulties were experienced in isokinetic sampling. The duct was vertical with an upward gas flow and an internal diameter of 0.43 m (17 in.).

Sample Point 2, which was one leg of the precipitator outlet, was highly inaccessible and was not regarded as a satisfactory sampling point for several reasons: (1) Sampling of only one leg of the precipitator required an assumption that both sides in the parallel configuration were operating identically, (2) Possible dust accumulation in the bottom of the duct could affect flow measurements, and (3) The location was too close to converging and diverging ducts for uniform particulate sampling.

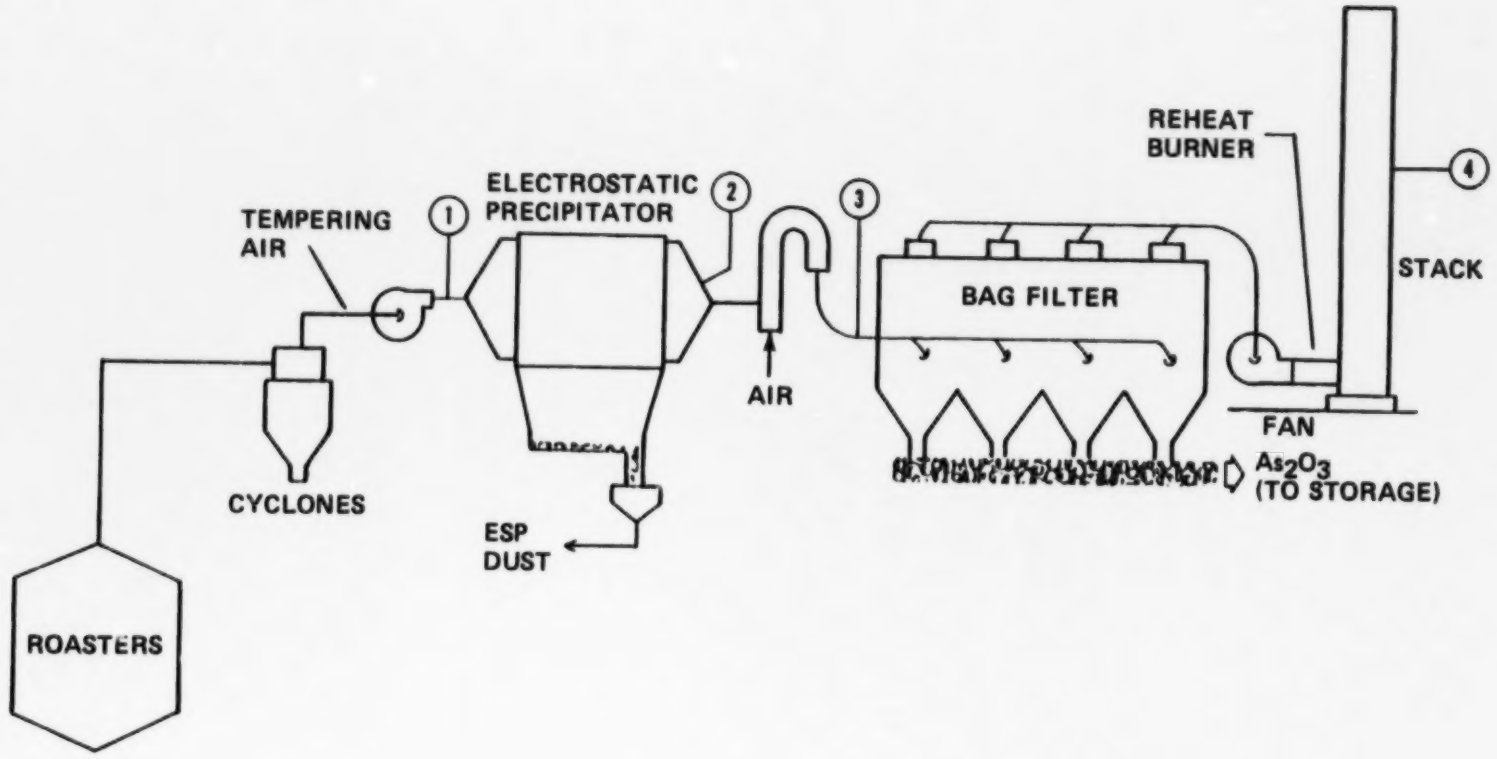

Figure 4. Sampling locations.

Access to this sample location was also very difficult due to physical restraints within the building housing the equipment. However, since the precipitator and mixer-cooler are very closely coupled, samples were taken from this 0.25 m (10 in.) square duct since this was the only possible sampling point for estimating particulate at the ESP outlet/mixer-cooler inlet.

Sample Point 3 at the outlet of the mixer-cooler provided data for the baghouse inlet. Gas flow was vertically downward through the 0.71 m (28-in.) duct.

Sample Point 4 in the stack provided data for the baghouse outlet. The internal diameter of the stack was 0.76 m (30-in.).

Insofar as possible, all samples were taken isokinetically to assure that representative measurements were made. There were some variations in operation during the test period that affected the sampling program; however, adequate data were obtained to evaluate the overall performance of the electrostatic precipitator and the baghouse.

A summary of plant operating data for the test period is shown in Table 3. These data show that the plant was in reasonably stable operation during the tests even though there was one operational shut-down during the test period, and the precipitator had an electrical malfunction near the end of the test period. (Data omitted).

TABLE 3. PLANT OPERATING DATA

	Avg.	Range
Freeboard Temperatures		
Reactor No. 1, °C	549	532-558
°F	1021	990-1037
Reactor No. 2, °C	511	503-508
°F	951	938-946
Air Flow-to-Wind Box		
Reactor No. 1, m^3/min (cfm)	34 (1200)	33.7-34.6 (1190-1220)
m/sec	34.0	33.7-34.6
Reactor No. 2, m^3/min (cfm)	26 (920)	24.4-28.3 (860-1000)
m/sec	26.1	24.4-28.3
ESP and Baghouse Temperatures		
ESP Inlet, °C	392	378-409
°F	737	713-768
ESP Outlet, °C	308	277-327
°F	586	531-620
Baghouse Inlet, °C	118	109-121
°F	245	229-250
Baghouse Outlet, °C	111	109-113
°F	232	228-236
Stack, °C	102	100-104
°F	216	212-219
Precipitator*		
AC Amps	10.1	9.5-10.5
AC Volts	418	413-423
DC Milliamps	40	35-45
DC Volts x 1000	57.3	56.2-58.6

* Excluding data at end of test period.

SECTION 5

PARTICULATE MEASUREMENTS

Modified Brink cascade impactors were operated at the ESP inlet and baghouse inlet (Sample Points 1 and 3), Andersen Mark III cascade impactors were operated at the precipitator outlet (Sample Point 2), and University of Washington Mark III (Pilat) cascade impactors were operated at the baghouse outlet (Sample Point 4). The collection substrates (glass fiber) used in the Brink and Andersen impactors were conditioned by acid washing in the laboratory to decrease the amount of substrate weight gain due to gas phase reactions. The collection substrates used in the University of Washington (Pilat) impactors were greased stainless-steel substrates which were prepared in the laboratory prior to use in the field. All impactor data obtained at Red Lake were reduced using a computer program described in EPA Report Number 600/7-78-042, A Computer-based Cascade Impactor Data Reduction System, by J.W. Johnson, G.I. Clinard, L.G. Felix, and J.D. McCain, March 1978. Details of the cascade impactors are given in the Appendix, Figures A-1, A-2, and A-3.

The impactor data collected at the ESP inlet sampling location are presented in Figure 5 as cumulative mass loading vs. particle size. Figure 6 presents the same data as cumulative percent vs. particle diameter. As can be seen from Figure 6, 50% of the particulate at the ESP inlet was less than 16 μm. A maximum particle diameter of 25 μm was used in the impactor data reduction program for each sampling location, since the size of the largest particle found in the cyclone catches of the Brink impactors operated at the ESP and baghouse inlets was 25 μm.

As indicated earlier, satisfactory particulate sampling could not be carried out at the ESP outlet; however, a limited number of impactor runs were made at the ESP outlet to approximate the loading of particulate less than two microns would be present at the outlet of the condenser in addition to that resulting from condensation (or desublimation). Figures 7 and 8 present data on the cumulative mass vs. particle size and cumulative percent vs. particle size at the ESP outlet. Figures 9 and 10 show the same data for the baghouse inlet and Figures 11 and 12 for the baghouse outlet.

Figure 7 shows that the mass loading of particulate below 2 microns diameter at the ESP outlet was less than 7×10^2 mg/ACM,

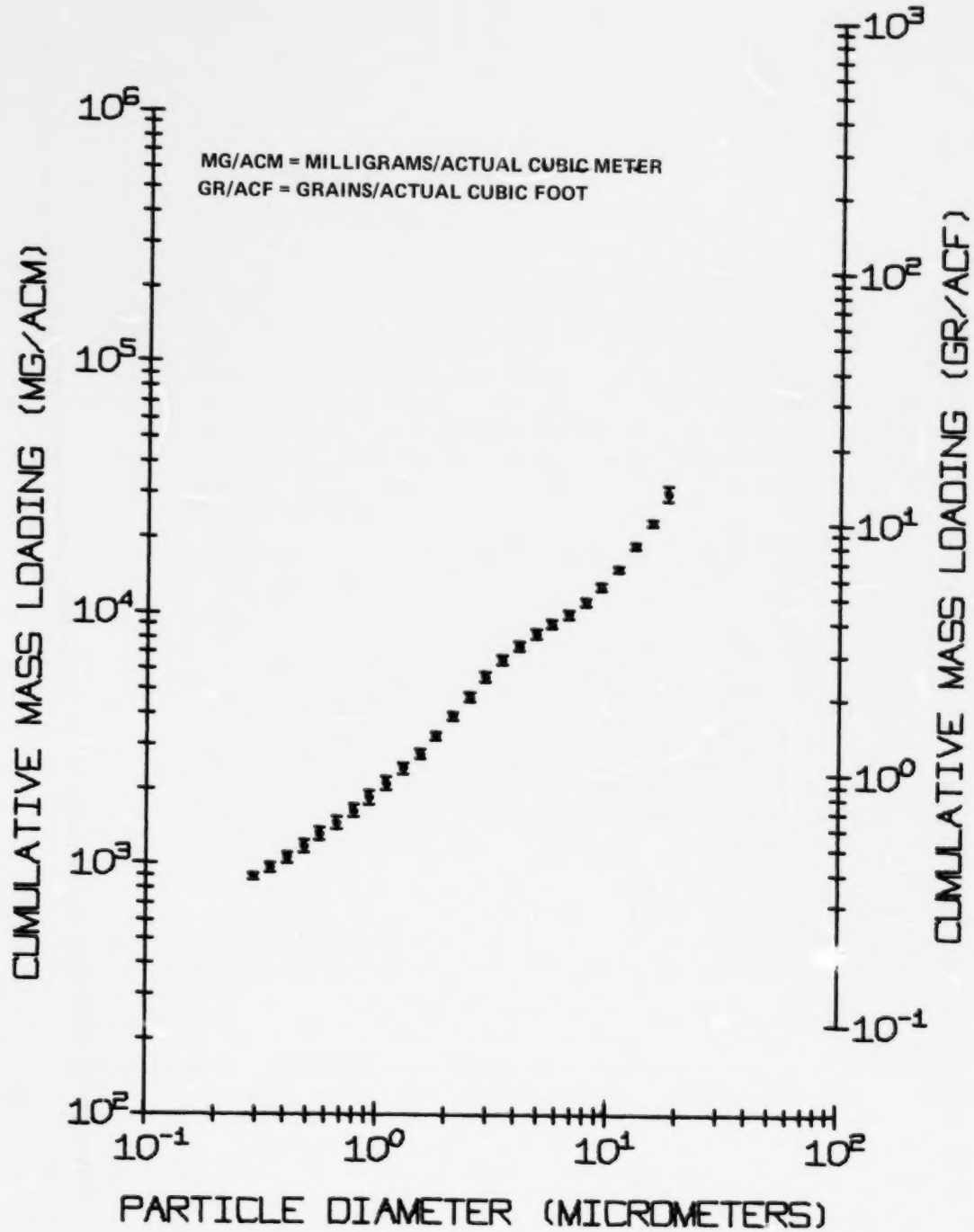

Figure 5. Average ESP inlet cumulative size distribution.

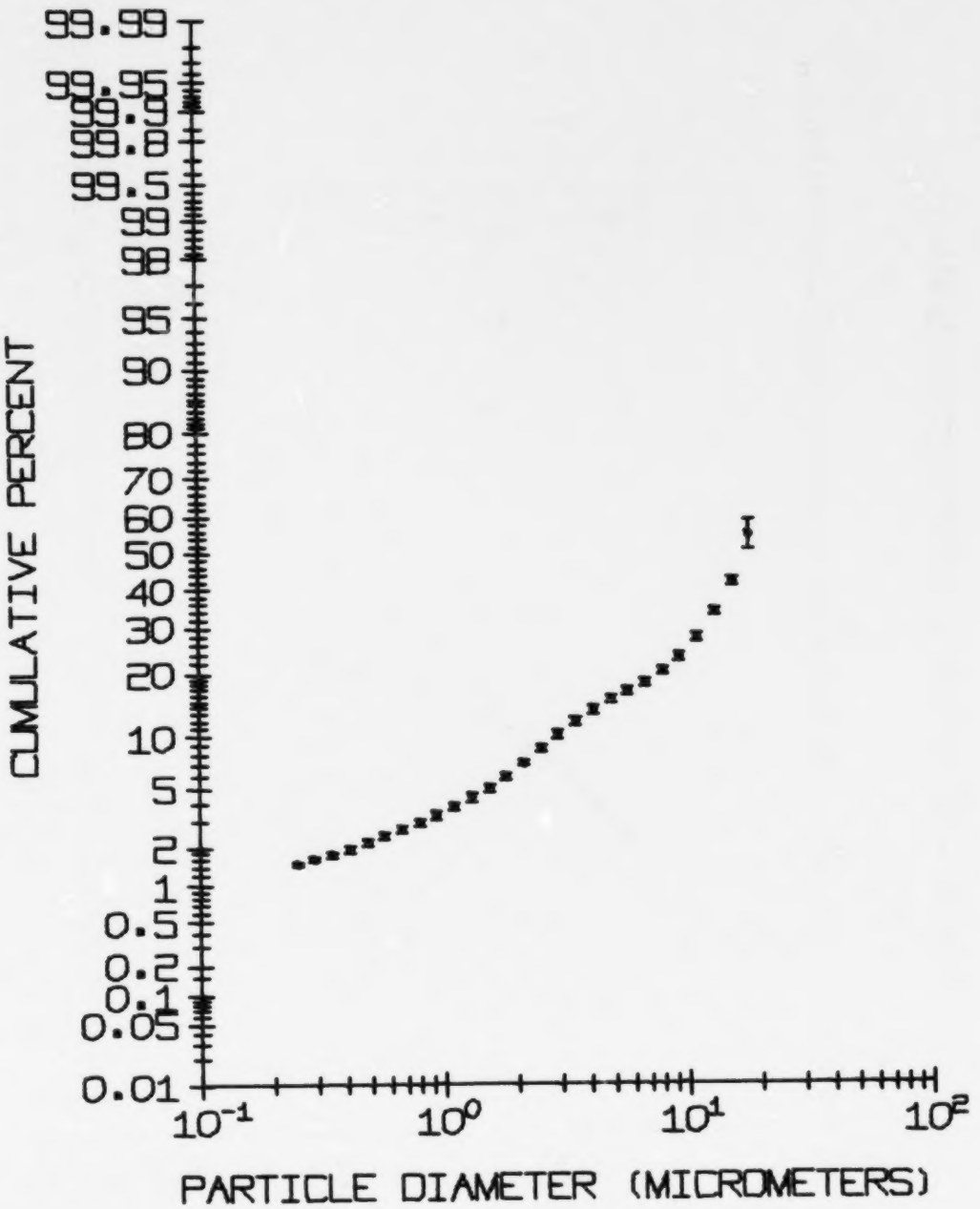

Figure 6. Average ESP inlet cumulative percent versus particle diameter.

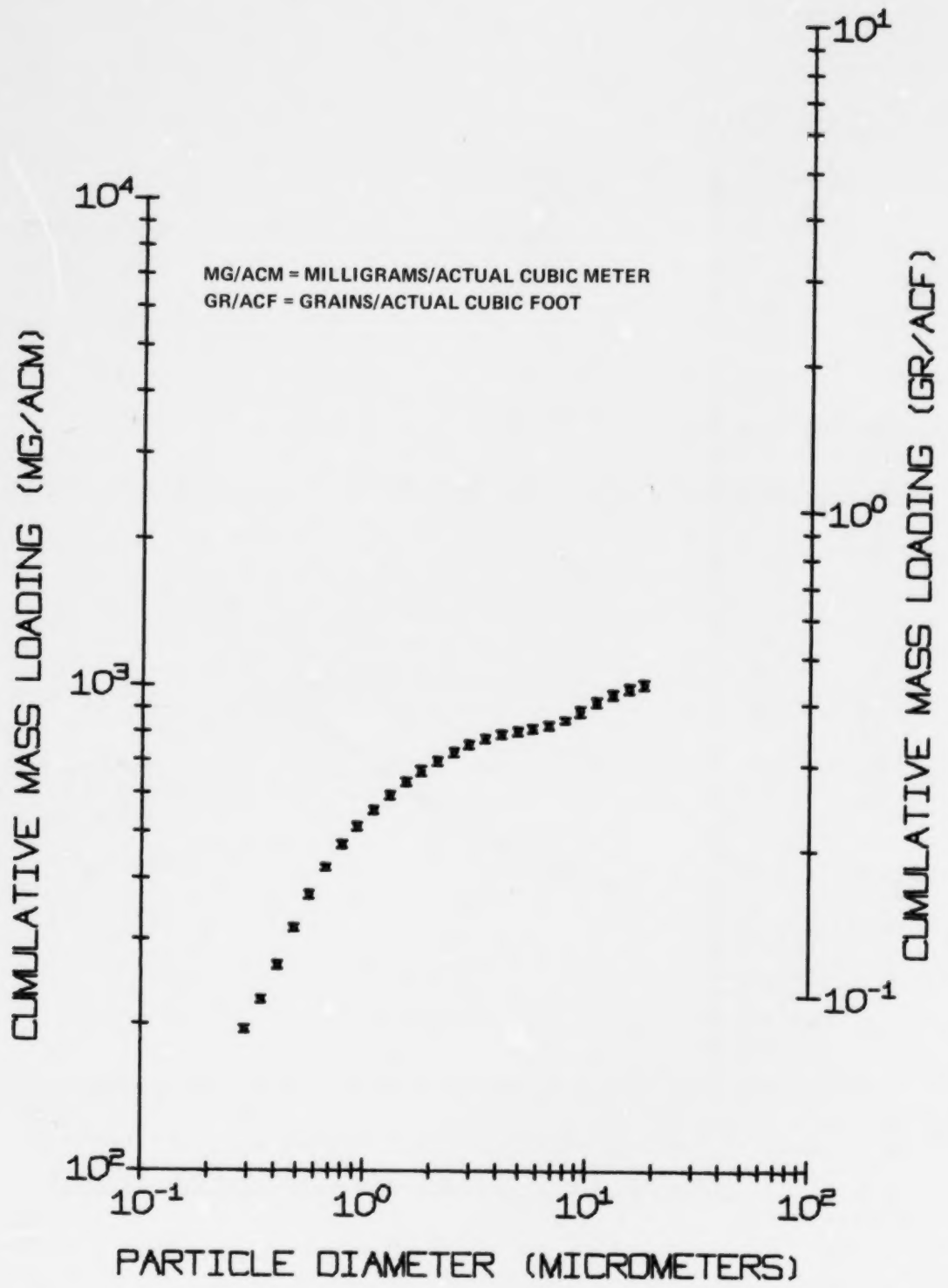

Figure 7. Average ESP outlet cumulative size distribution.

and Figure 8 indicates that this amounted to about 60% of the total mass at the ESP outlet. The data for the baghouse inlet, after addition of quench air in the mixer-cooler, in Figures 9 and 10 show that the mass loading of particulate below 2 microns at the baghouse inlet was about 7×10^{3} mg/ACM and also amounted to about 60% of the total mass at this point. Figures 11 and 12 show that the particulate below 2 microns at the baghouse outlet was less than 5×10^{-2} mg/ACM or about 10% of the total particulate emission. Data from Figures 9 and 11 show (for example) that the baghouse collection efficiency for particulate below 2 microns was greater than 99.99%. This is further illustrated in Figure 13 which shows the baghouse collection efficiency and penetration as a function of particle size.

Figure 13 shows that a minimum collection efficiency of about 99.8% occurred at about 5 microns with another "minimum point" at about 0.5 microns. This bimodal distribution is not abnormal for baghouse performance. Other workers in the field have attributed the increased penetration (decreased collection efficiency) at around 0.5 microns to the lack of inertial or diffusional collection mechanisms, and the increase around 5 microns has been attributed to seepage[3].

One concern in the evaluation of data from the ESP and baghouse was that carryover from the ESP would partially obscure performance of the mixer cooler and provide erroneous data on particulate at the inlet to the baghouse. However, data in Figure 7 shows that the mass loading of particulate below 2 microns diameter at the ESP outlet was less than 7×10^{2} mg/ACM at a gas flow rate of 3888 dscm/hr (from Table 5). Figure 9 shows that the mass loading of particulate below 2 microns diameter at the baghouse inlet was about 7×10^{3} mg/ACM at a gas flow rate of about 16,779 dscm/hr. The ratio of these numbers ($7 \times 10^{2} \times 3888 \div 7 \times 10^{3} \times 16{,}779$) indicates that less than five percent of the particulate entering the baghouse was particulate at the ESP outlet; therefore, greater than 95 percent of the particulate entering the baghouse resulted from condensation in the mixer-cooler, and the data shown in Figures 9 to 13 are accurate reflections of the particulate formed in the mixer-cooler and removed by the baghouse. The mass loadings from all the impactor runs used in the data reduction programs are presented in Table 4. Based on these data, the average particulate collection efficiency of the baghouse exceeds 99.9%. Data from the mass sampling trains and the trace element trains also indicate an average efficiency above 99.9% for the baghouse.

Impactor data for the precipitator show a particulate collection efficiency of 98.3%. Trace element data (collected independently by Radian) show a somewhat lower precipitator efficiency of 97.1%. However, all data agree that the overall particulate collection efficiency of the "hot ESP/cold baghouse system" exceeds 99.9%.

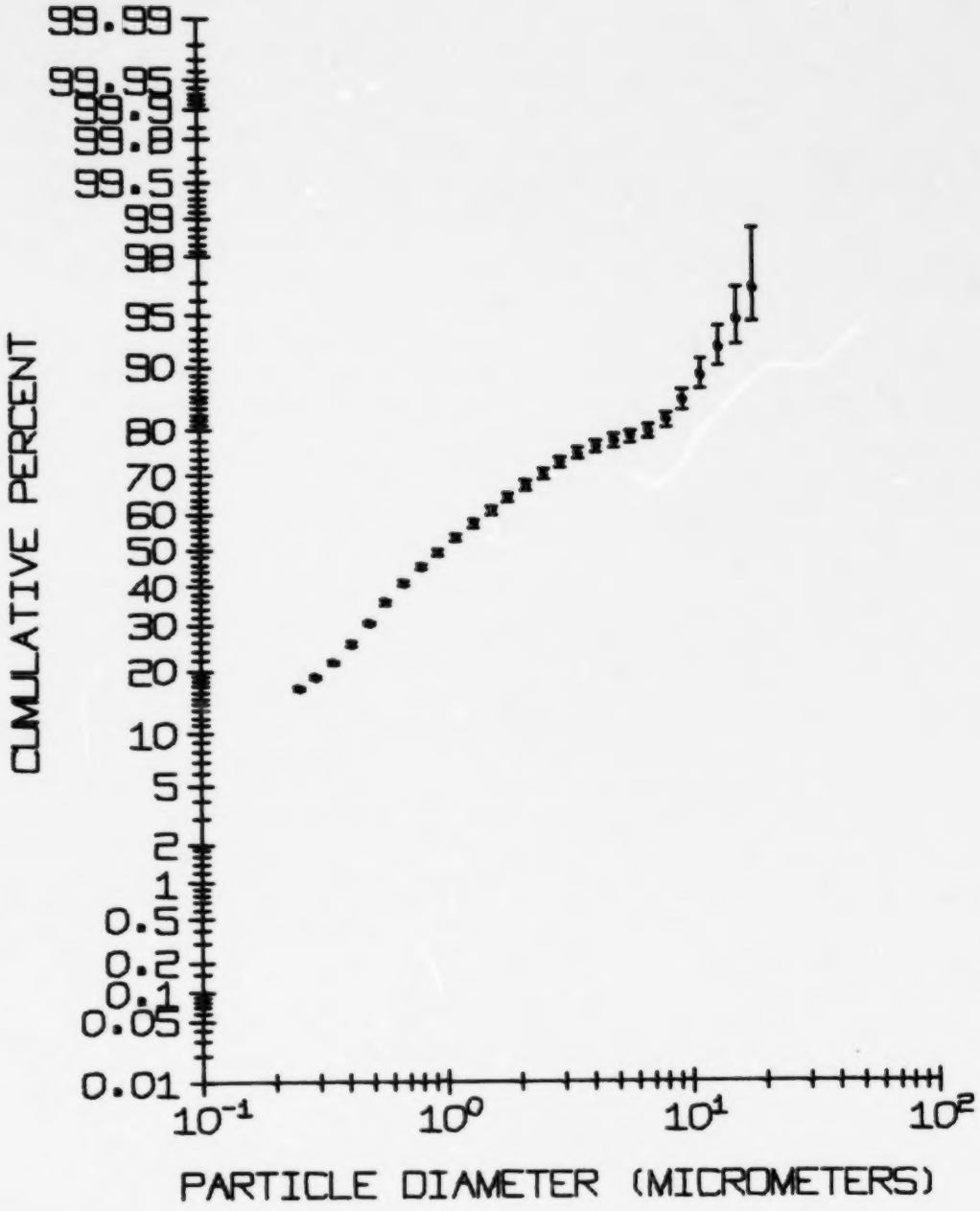

Figure 8. Average ESP outlet cumulative percent versus particle diameter.

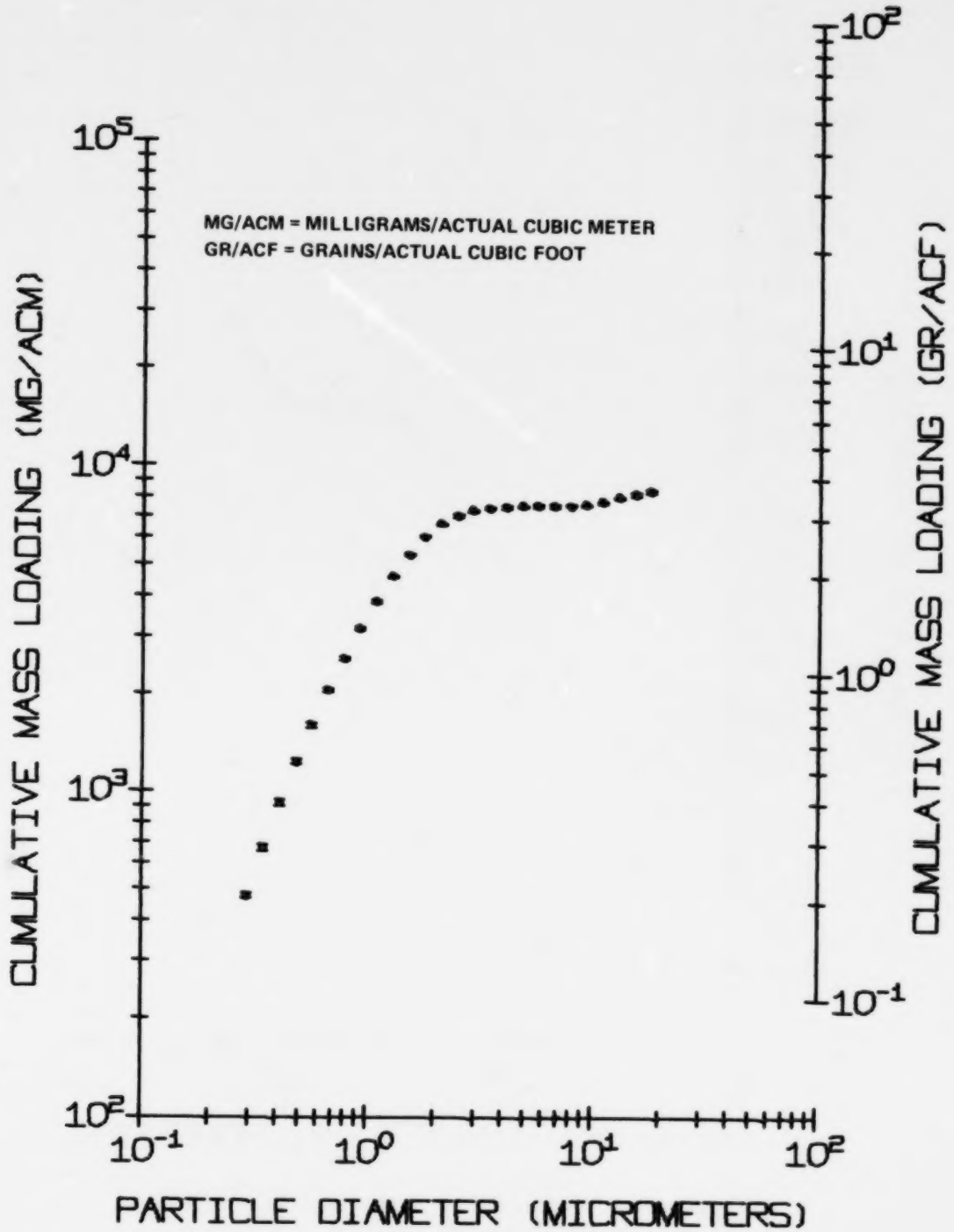

Figure 9. Average baghouse inlet cumulative size distribution.

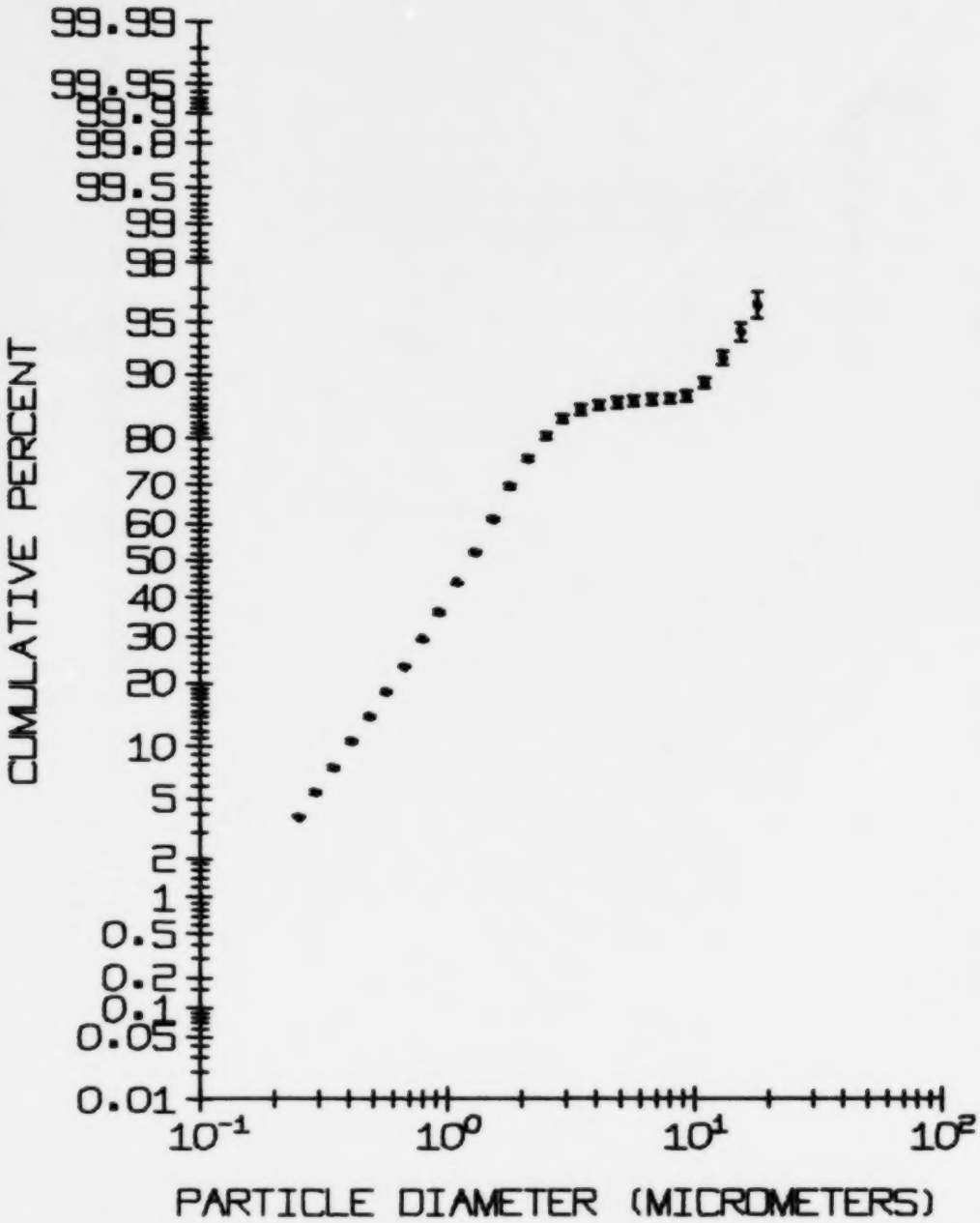

Figure 10. Average baghouse inlet cumulative percent versus particle diameter.

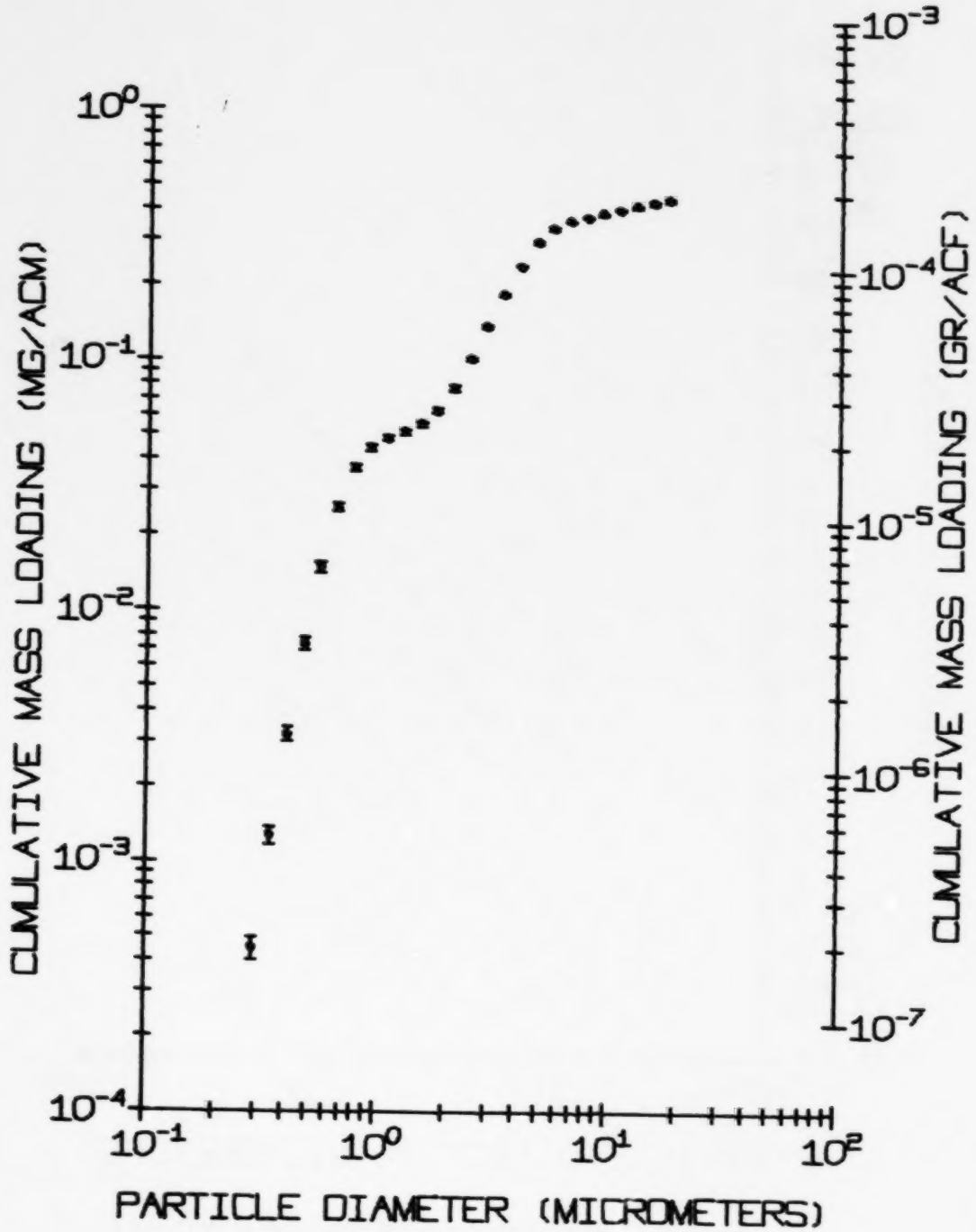

Figure 11. Average baghouse outlet cumulative size distribution.

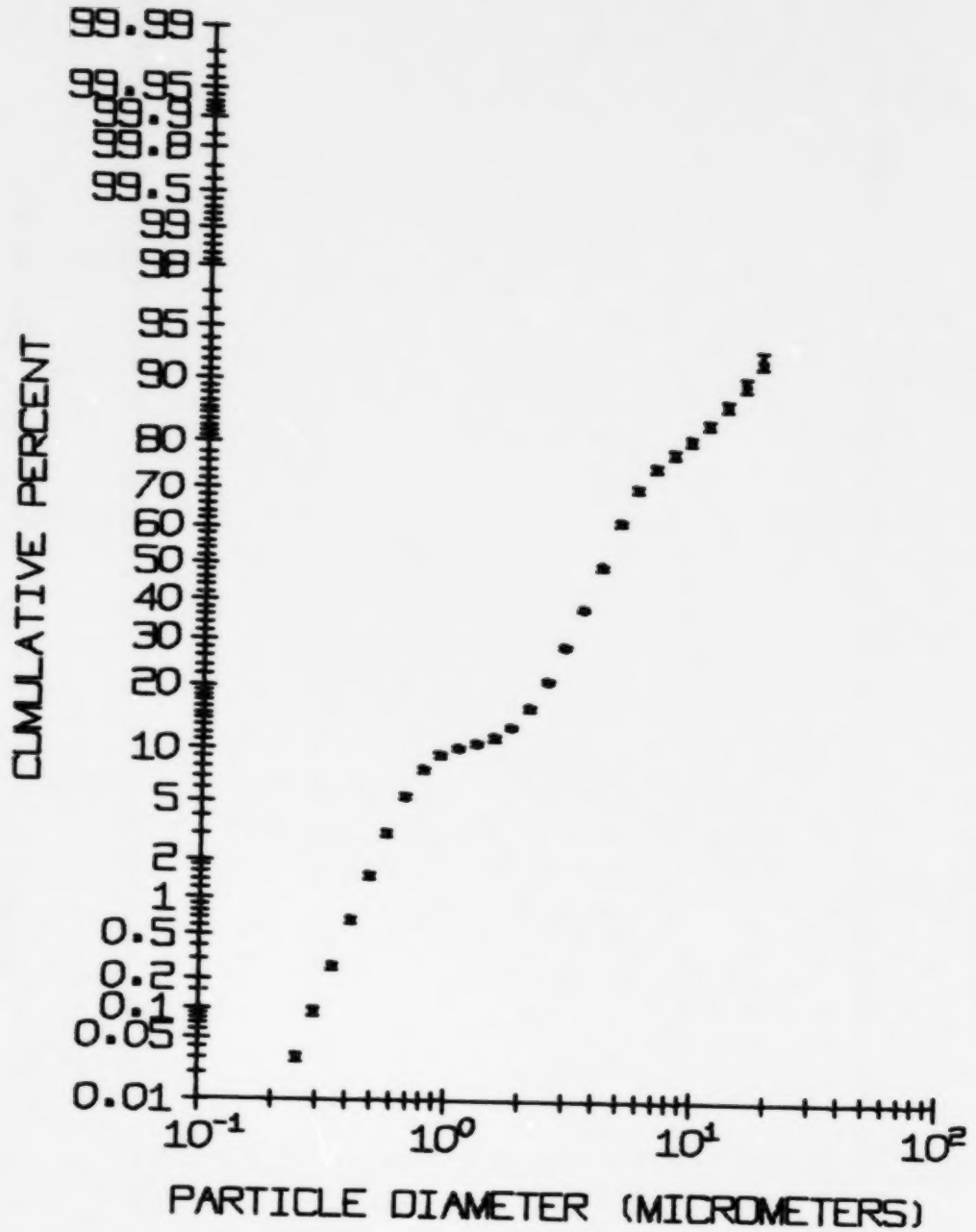

Figure 12. Average baghouse outlet cumulative percent versus particle diameter.

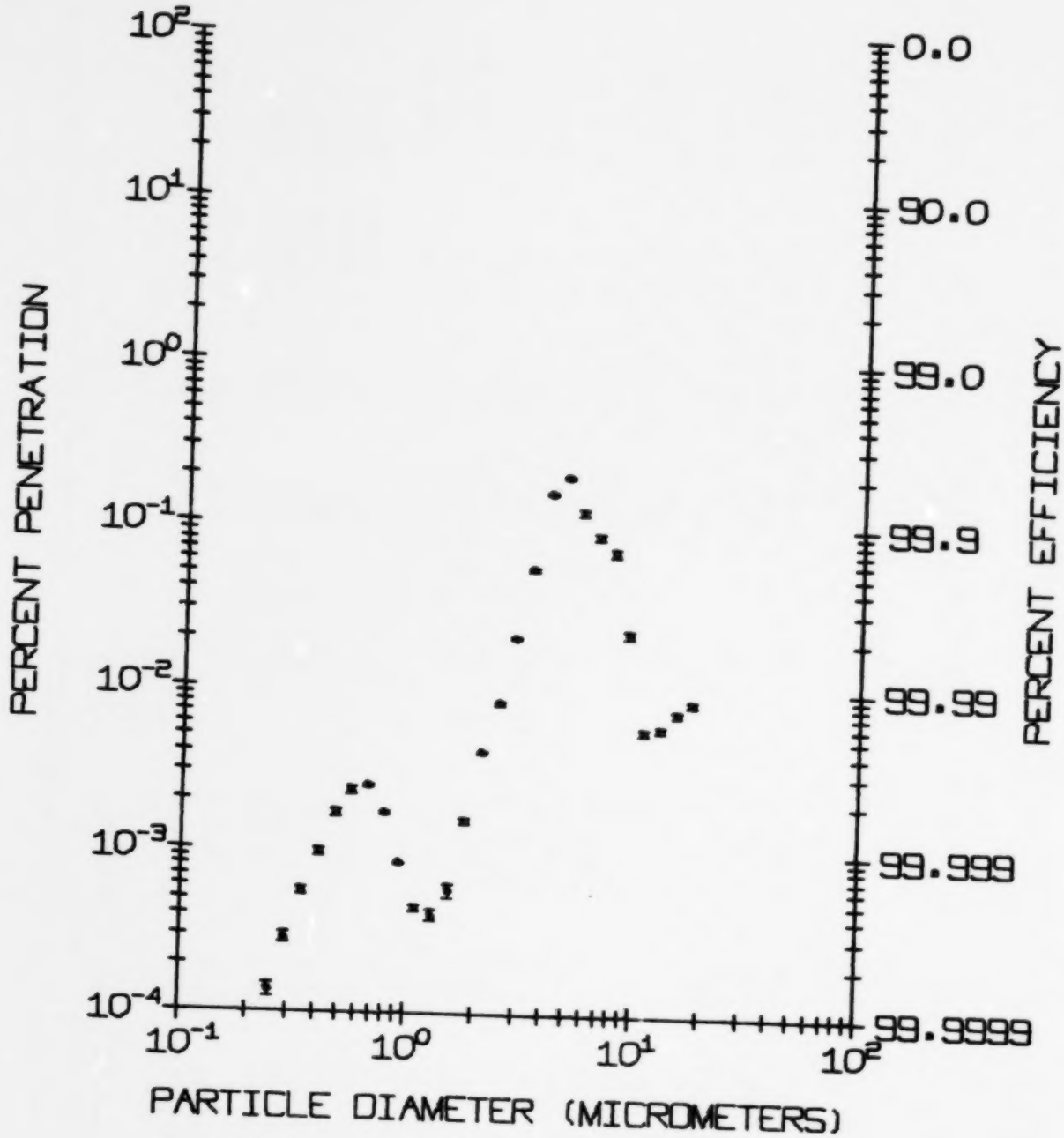

Figure 13. Baghouse particulate collection efficiency.

TABLE 4. IMPACTOR MASS LOADINGS

Location	Run#	Date	Sample Time, min	Impactor Temp. °F	°C	Mass Loading gr/SCF	mg/SCM
ESP Inlet	RLI-3	9/19/78	4	600	316	18.73	4.29×10^4
ESP Inlet	RLI-6	9/20/78	4	580	304	114.82	2.63×10^5
ESP Inlet	RLI-7	9/20/78	4	555	291	50.36	1.15×10^5
ESP Inlet	RLI-8	9/20/78	4	560	293	58.82	1.35×10^5
Bghs Inlet	RLI-12	9/21/78	4	244	118	5.25	1.20×10^4
Bghs Inlet	RLI-13	9/21/78	4	230	110	5.07	1.16×10^4
Bghs Inlet	RLI-14	9/21/78	4	225	107	5.34	1.22×10^4
Bghs Inlet	RLI-16	9/25/78	4	220	104	4.56	1.04×10^4
Bghs Inlet	RLI-17	9/25/78	4	220	104	5.04	1.15×10^4
Bghs Inlet	RLI-18	9/25/78	4	225	107	5.14	1.18×10^4
Bghs Inlet	RLI-19	9/25/78	4	230	110	5.80	1.33×10^4
Bghs Inlet	RLI-21	9/26/78	4	228	109	4.55	1.04×10^4
Bghs Inlet	RLI-22	9/26/78	4	243	117	5.19	1.19×10^4
Bghs Inlet	RLI-23	9/26/78	4	228	109	5.97	1.37×10^4
Bghs Inlet	RLI-24	9/26/78	4	243	117	6.70	1.53×10^4
Bghs Outlet	RLO-1	9/19/78	360	228	109	0.00024	0.550
Bghs Outlet	RLO-2	9/20-21/78	960	226	108	0.00029	0.657
Bghs Outlet	RLO-3	9/20-21/78	960	226	108	0.00028	0.642
Bghs Outlet	RLO-5	9/25/78	480	228	109	0.00027	0.621
Bghs Outlet	RLO-6	9/25/78	480	228	109	0.00029	0.667
ESP Outlet	RLO-8	9/26/78	4	575	302	1.017	2.33×10^3
ESP Outlet	RLO-9	9/26/78	4	575	302	1.079	2.47×10^3

Baghouse efficiency = 99.99+%
ESP efficiency = 98.3%

SECTION 6

GAS SAMPLING AND ANALYSIS

Two types of modified EPA Method 5 sampling trains were used at each sampling site. These two trains differed from each other only in the number of impingers and the solutions in them. An illustrative gas sampling train is shown in Figure 14.

The trace element train consisted of 7 modified Smith-Greenburg impingers operated in an ice bath. Impingers 1 and 2 contained 10% HNO_3, impinger 3 was empty, impingers 4 and 5 contained 10% NaOH, impinger 6 contained 6% H_2O_2, and impinger 7 contained silica gel. Basic and neutral species were absorbed in the HNO_3 and acid species in the NaOH. The gas was then scrubbed in H_2O_2 and dried by the silica gel and passed into the control console. Lear Siegler PM-100 stack sampling consoles were used. These contained all flow controls, temperature and pressure indicators, a pump, and a dry gas meter.

The sulfur oxide train contained only five impingers. The first contained 80% isopropanol for absorption of SO_3. The second and third contained 6% H_2O_2 for absorbing SO_2, the fourth was empty, the fifth contained silica gel.

Both trains contained in-stack and out-of-stack filters which were used to collect particulate (in-stack) and vaporous arsenic trioxide which condensed in the probe after removal of other particulate (out-of-stack).

After sampling, extensive cleaning of the sampling train was required to remove As_2O_3 which had condensed in the probe and glassware. The nozzle, probe, and glassware were rinsed with H_2O, acetone, and NaOH solution to dissolve As_2O_3. Since As_2O_3 is condensable and adheres to walls of sampling equipment, a rigid washing protocol was used to assure maximum recovery from the sampling trains.

Solid (particulate) from the in-stack filter and gaseous components from the out-of-stack filter and the trace element sampling train were analyzed for four elements: arsenic, antimony, lead, and selenium. Gas flow velocities, gas analyses, temperatures, and particulate grain loadings were also determined at each sample point.

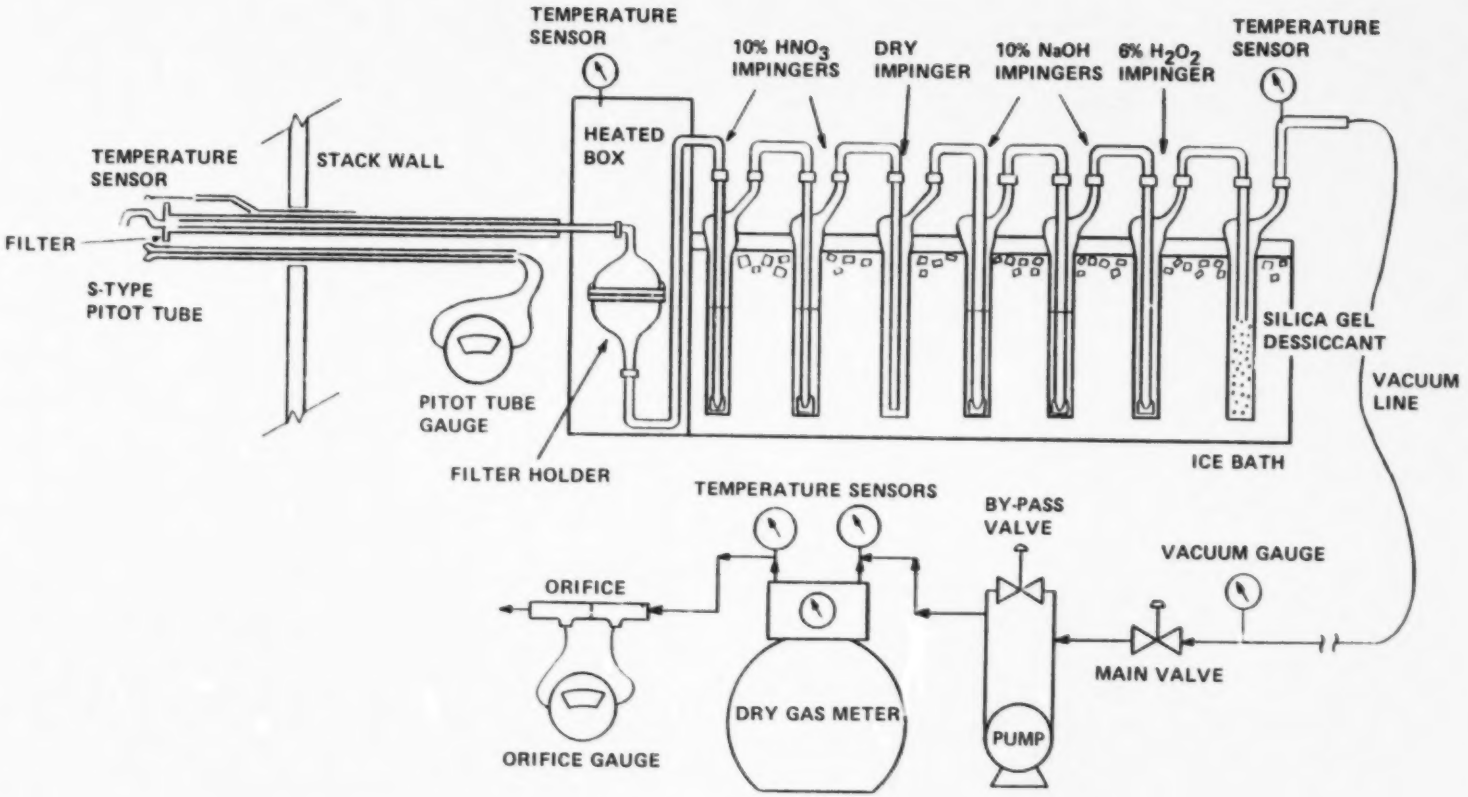

Figure 14. Trace element gas sampling train.

The trace element analyses (for As, Sb, Pb, and Se) were based on atomic absorption (AA) using flame aspiration and a graphite furnace attachment. Solid samples were digested in $HF/HNO_3/HCl$ acid mixtures. Liquid samples and digested solids were aspirated directly into the air-acetylene flame of the AA using standard calibration solutions[4] and heating programs[5].

Gas analyses were based on the use of the sulfur oxide (SOX) absorption train (for SO_2 and SO_3) and the use of Fyrite solutions (for O_2 and CO_2). The impinger solutions from the SOX train were analyzed by liquid ion chromatography[6] and moisture was determined by weight gain (corrected for SO_2 absorption) in the impinger train. Since Fyrite also absorbs SO_2 along with CO_2, values shown for CO_2 are corrected.

A summary of the gas stream measurements, gas analyses, and trace element analyses are shown in Table 5. Individual measurements of gas flows and grain loadings are shown in Table 6. It should also be noted that the difference in arsenic levels shown in Table 5 for the ESP outlet and baghouse inlet reflect variations in process conditions (not on-stream changes) since the ESP and baghouse samplings were not made simultaneously.

The grain loading data in Table 5 show a particulate removal efficiency of about 97.1% for the hot ESP and better than 99.9% for the baghouse (based on in-stack measurements used with the trace element trains). Further, based on all particulate in the system (combining ESP inlet and condensed particulate at the baghouse inlet), the overall particulate removal efficiency of the combined ESP-baghouse system was 99.99+%.

Lead and selenium analyses in Table 5 indicate removal efficiencies for these elements of only about 90%; however, the amounts of lead and selenium present in the system were very low and their combined emissions were less than 0.02 Kg/hr (0.04 lb/hr). Antimony removal efficiency was about 99.5%, but the Sb emissions from the baghouse were only about 0.01 Kg/hr. For the more prevalent trace element, arsenic, the overall efficiency of the baghouse and ESP combined was about 99.9%, with the major portion emitted being in the gaseous (rather than particulate) form.

A more detailed analysis of the solid and vapor distribution for arsenic is shown in Table 7. This table shows that most of the arsenic (As_2O_3) entering the precipitator is in a volatile form and relatively little is caught in the ESP. Particulate arsenic at the ESP inlet is shown to be only about 3% of the total arsenic in the stream and most of this is collected in the precipitator. Comparison of the data for arsenic in the ESP inlet and outlet indicates that about 15% is collected in the ESP; however, as indicated earlier, measurements at the ESP outlet were not considered to be highly reliable. Other data

TABLE 5. GAS STREAM MEASUREMENTS AND TRACE ELEMENTS DISTRIBUTION

	ESP Inlet	ESP Outlet	Baghouse Inlet	Baghouse Outlet
Temperature				
°C	380	327	116	113
°F	716	621	240	236
Velocity				
m/sec	21.3	21.9	16.5	16.9
ft/sec	70.0	71.9	54.0	55.3
Grain Loading				
grams/dscm	35.2	1.01	11.40	0.00094
grains/dscf	15.4	0.442	4.98	0.00041
Flow Rate				
dscm/hr	3899	3888	16,779	19,817
dscf/hr	137,680	137,314	592,526	699,833
Trace Elements (total)				
As-Kg/hr	179	152*	105*	0.20
-lb/hr	393	334	232	0.44
Pb-Kg/hr	0.14	0.05	-	0.015
-lb/hr	0.32	0.11	-	0.034
Sb-Kg/hr	2.1	0.40	-	0.011
lb/hr	4.7	0.88	-	0.025
Se-Kg/hr	0.0045	0.0017	-	0.0004
-lb/hr	0.010	0.0037	-	0.0009
Gas Analysis				
$\%O_2$	11.3	13.9	19.0	19.5
$\%SO_2$	8.2	5.9	1.4	1.4
$\%H_2O$	22.8	21.8	5.5	5.6
$\%CO_2$	0.3	1.8	0.8	0.0
ppm SO_3	336	791	187	<2

* Not measured simultaneously.

TABLE 6. GAS FLOW DATA
(Trace element trains)

Site	Date	Temperature		Velocity		Grain Loading	
		°F	°C	ft/sec	m/sec	gr/dscf	grams/dscm
ESP Inlet	9-21	704	373	67.3	20.5	-	-
"	9-21	712	378	66.3	20.2	-	-
"	9-25	715	379	69.5	21.2	16.16	37.0
"	9-25	715	379	59.8	18.2	13.68	31.3
"	9-26	720	382	74.7	22.8	17.20	39.4
"	9-26	728	387	76.4	23.3	16.73	38.3
"	9-26	718	381	76.1	23.2	13.35	30.5
Avg. ESP Inlet	-	716	380	70.0	21.3	15.4	35.2
ESP Outlet	9-18	665	352	69.0	21.0	-	-
"	9-19	643	339	62.3	19.0	-	-
"	9-20	639	337	72.3	22.0	-	-
"	9-20	633	334	77.1	23.5	0.301	0.69
"	9-21	611	322	76.3	23.3	0.584	1.34
"	9-21	638	337	76.7	23.4	0.494	1.13
"	9-25	570	299	69.5	21.2	0.376	0.86
"	9-25	590	310	70.0	21.3	0.454	1.04
"	9-25	600	316	73.9	22.5	-	
Avg. ESP Outlet	-	621	327	71.9	21.9	0.442	1.01
Bghs. Inlet	9-18	249	121	61.2	18.7	-	-
"	9-19	242	117	54.0	16.5	-	-
"	9-20	236	113	55.5	16.9	-	-
"	9-20	246	119	51.8	15.8	4.437	10.15
"	9-27	233	112	53.7	16.4	6.273	14.35
"	9-27	236	113	51.5	15.7	5.189	11.87
"	9-27	237	114	50.0	15.2	4.007	9.17
Avg. Bghs. Inlet	-	240	116	54.0	16.5	4.98	11.40
Bghs. Outlet	9-26	227	108	54.0	16.5	-	
"	9-26	238	114	51.1	15.6	0.00036	0.00082
"	9-26	238	114	57.4	17.5	0.00019	0.00043
"	9-27	-	-	59.6	18.2	0.00071	0.00162
"	9-27	242	117	54.2	16.5	0.00037	0.00085
Avg. Bghs. Outlet	-	236	113	55.3	16.9	0.00041	0.00094

TABLE 7. SOLID AND VAPOR DISTRIBUTION OF As
(Trace element trains)

Phase	ESP Inlet	ESP Outlet	Baghouse Inlet	Baghouse Outlet
SOLID				
gm/dscm	1.21	2.68×10^{-2}	6.20	1.8×10^{-3}
lb/dscf	7.58×10^{-5}	1.67×10^{-6}	3.87×10^{-4}	1.1×10^{-7}
Kg/hr	4.7	0.10	104	0.02
lb/hr	10.4	0.23	229	0.07
VAPOR				
gm/dscm	44.6	39.0	7.82×10^{-2}	9.14×10^{-3}
lb/dscf	2.78×10^{-3}	2.43×10^{-3}	4.89×10^{-6}	5.71×10^{-7}
Kg/hr	174	152	1.31	1.81×10^{-1}
lb/hr	383	334	2.90	3.99×10^{-1}
TOTAL				
Kg/hr	179	152	105	0.20
lb/hr	393	334	232	0.44

(analysis of the ESP dust) also indicate that the particulate arsenic collected in the ESP was less than 2-3% of the total in the system. In any event, since the primary function of the ESP is to recover metal values with minimum collection of arsenic, the data obtained during the test program confirmed that the system was operating effectively.

Data in Table 7 also show that most of the volatile arsenic (as As_2O_3)that passed through the hot ESP was condensed in the mixer-cooler so that nearly 99% was in particulate form at the baghouse inlet, and the collection efficiency of particulate arsenic in the baghouse was greater than 99.95%. Overall arsenic collection efficiency in the baghouse was somewhat lower at 99.8% due to the passage of volatile As_2O_3. The effectiveness of the baghouse for recovery of particulate arsenic is further illustrated by the data for the baghouse outlet which shows a particulate emission of only 0.02 Kg/hr. Total arsenic emissions (including both volatiles and particulates) were about 0.2 Kg/hr.

SECTION 7

OTHER ANALYSES

In addition to the data obtained with the trace element trains (reported in the previous section), analyses were made of the roaster feed, calcine, the ESP dust, and the baghouse dust. Typical analyses are shown in Table 8. Initially, it was anticipated that these values could be used in conjunction with the in-stack particulate analyses and the trace-element-train analyses to develop detailed material balances over the entire system. However, since the discharge rates from hoppers of the ESP and baghouse were not measured, no direct measurements of the precipitator and baghouse catches could be made that were directly comparable to the trace-element-train measurements. Indirect material balances can be made using the grain loading and flow rates from Table 5 and the analyses from Table 8. The calculated precipitator catch based on these data was about 135 Kg/hr (300 lb/hr) with about 2 Kg/hr (5 lb/hr) as arsenic. Similarly, the calculated baghouse catch was about 190 Kg/hr (420 lb/hr) with about 130 Kg/hr (287 lb/hr) as arsenic. These calculations further illustrate that the control system was operating essentially as designed, since less than 2% of the total arsenic was collected in the hot ESP and the major portion was collected in the baghouse.

The partial pressures of As_2O_3 in the various gas streams are shown in Table 9 in comparison to the vapor pressures of As_2O_3 at the temperatures of the sample points. The data show that the partial pressures of As_2O_3 at the inlet and outlet of the ESP are substantially below the equilibrium vapor pressure which confirms that no significant condensation should occur in the ESP at normal operating temperatures. The calculated partial pressure at the baghouse inlet, however, exceeds the equilibrium vapor pressure at this point. Since this sampling point was immediately following the mixer-cooler, it is possible that the As_2O_3 volatiles at this stage were supersaturated but reached equilibrium in passage through the baghouse. In any event, the final partial pressure (and emission) of volatile As_2O_3 from the baghouse is exactly what would be predicted from vapor pressure data.

Samples of the ESP and baghouse dusts were also examined using an ETEC Omniscan scanning electron microscope (SEM) and

TABLE 8. TRACE ELEMENT ANALYSES

	Arsenic, %	Lead, ppm	Antimony, ppm	Selenium, ppm
Roaster Feed	2.3	283	2115	6
Calcine	1.1	353	1530	8
ESP Dust	1.5	518	3650	53
Baghouse Dust	68.3	11	4580	<2

TABLE 9. As_2O_3 PARTIAL PRESSURES

Location	Temperature (°C)	Partial Pressure* (mmHg)	Vapor Pressure** (mmHg)
ESP Inlet	380	5.3	300
ESP Outlet	327	4.7	80
Baghouse Inlet	116	9.4×10^{-3}	1.5×10^{-3}
Baghouse Outlet	113	1.0×10^{-3}	1.0×10^{-3}

* Based on data in Table 7

** CRC Handbook of Chemistry and Physics, 50th Edition (1969) and Behrens, R. G. and Rosenblatt, G. M., "Vapor Pressure and Thermodynamics of Octahedral Arsenic Trioxide (Arsenolite)," J. Chem. Thermodynamics, 4, 175-190 (1972)

were qualitatively analyzed using a Princeton Gamma Tech energy dispersive X-ray analyzer. Figures 15 and 16 are SEM photographs of the ESP and baghouse solids respectively. The right side of each photograph is an enlargement of the indicated left field.

The ESP solids appear to contain a variety of crystal sizes, shapes, and colorations (as would be expected from the nature and composition of the particulate). By contrast, the baghouse solids appear to be uniform in color and particle size, except for agglomeration of small particles.

Scans of the energy dispersion X-ray analyses for the ESP and baghouse solids are given in Figures 17 and 18, respectively. The major peaks in the ESP solids were identified as As, Al, Si, S, K, Ca, and Fe. The only major element found in the baghouse solids was As.

To obtain information on the crystalline species in the dusts, the ESP and baghouse solids were analyzed by X-ray powder diffraction using a Siemens X-ray Diffractometer with nickel filtered CuKα radiation.

The X-ray diffraction pattern obtained for the ESP sample is given in Figure 19. The peaks on the diffraction pattern were identified as As_2O_3, SiO_2, Fe_3O_4, Fe_2O_3, or as unknown. The d-spacings in Angstroms, Å, for the peak assignments are included on the diffraction pattern. The ESP sample diffraction pattern for crystalline phases showed the presence of Fe_3O_4 (magnetite), Fe_2O_3 (hematite), SiO_2 (alpha quartz), and minor amounts of As_2O_3 (arsenolite). The three major peaks at 9.40, 3.11, and 2.88 Å that could not be positively assigned are believed to be calcium aluminum silicate.

The diffraction pattern for the baghouse dust is given in Figure 20. The only crystalline phase identified was arsenolite. Several small peaks at 6.18, 3.93, 3.53, and 3.35 Å could not be assigned.

Spark Source Mass Spectrometry (SSMS) was also used to provide semiquantitative analyses of the ESP and baghouse dusts. These data were to be used as a guide for analysis of other potentially volatile materials (other than As, Sb, Pb, and Se); however, no additional quantitative analyses were made since the analyses for antimony (Table 5), which was shown to be a major component in both streams by SSMS, showed very low concentrations. SSMS data metal components in the dusts at concentrations above 1 ppm are given in Table 10.

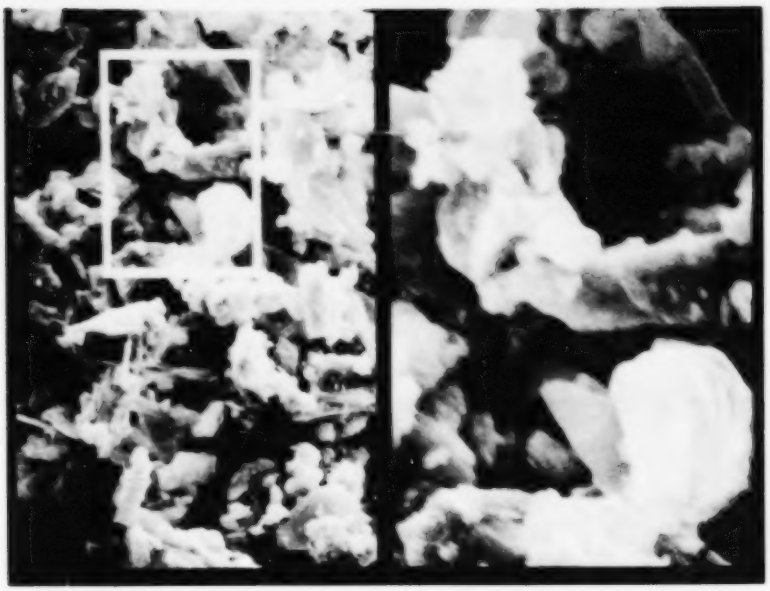

Figure 15. SEM Photograph of ESP Solids (1410X Magnification)

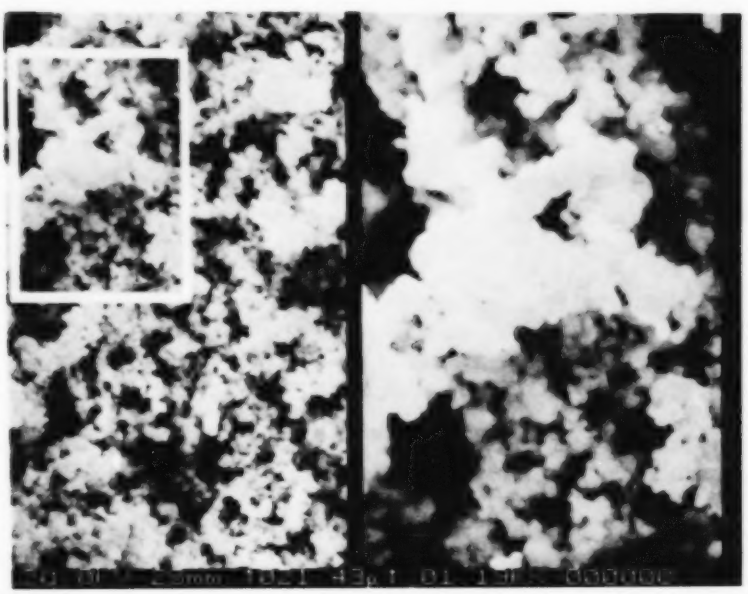

Figure 16. SEM Photograph of Baghouse Solids (1190 X Magnification)

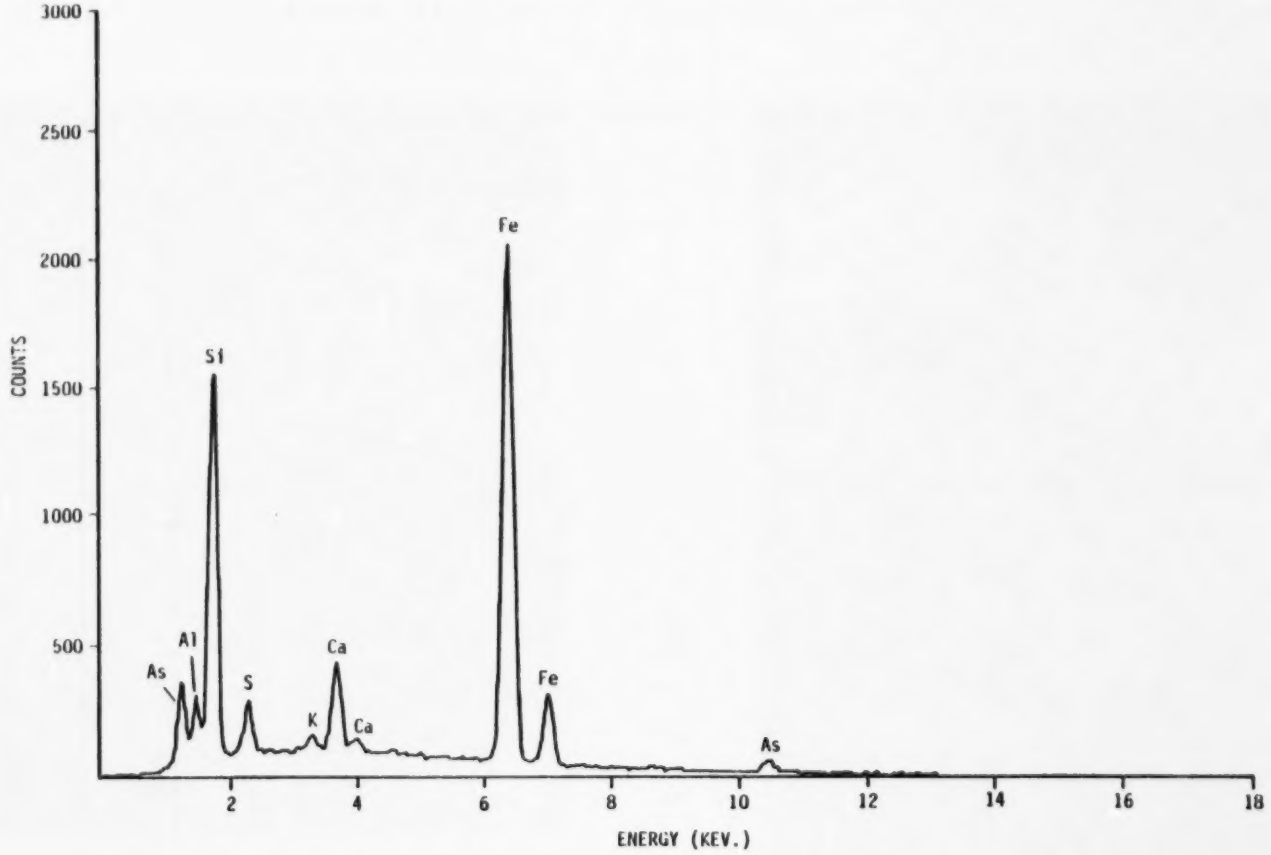

Figure 17. Energy dispersive X-ray analysis of ESP solids.

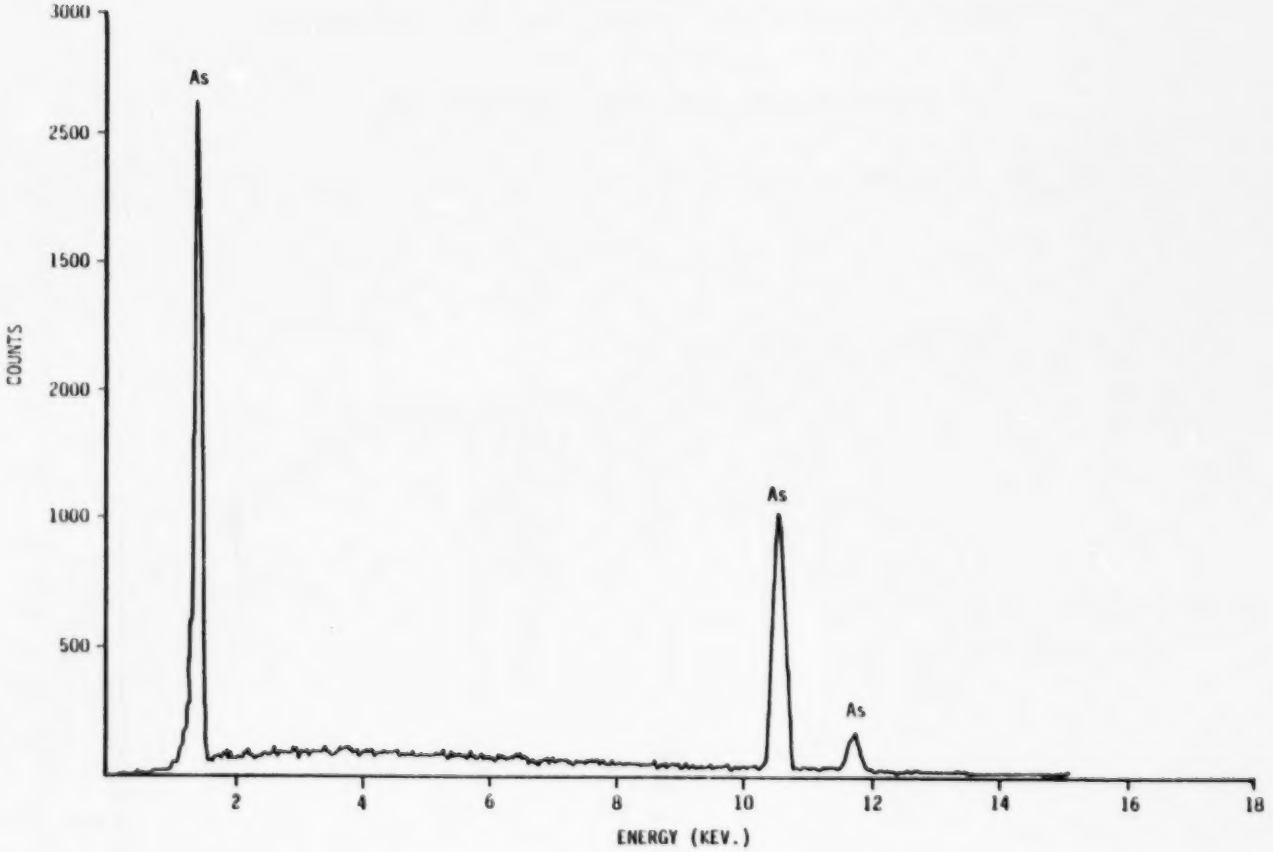

Figure 18. Energy dispersive X-ray analysis of baghouse solids.

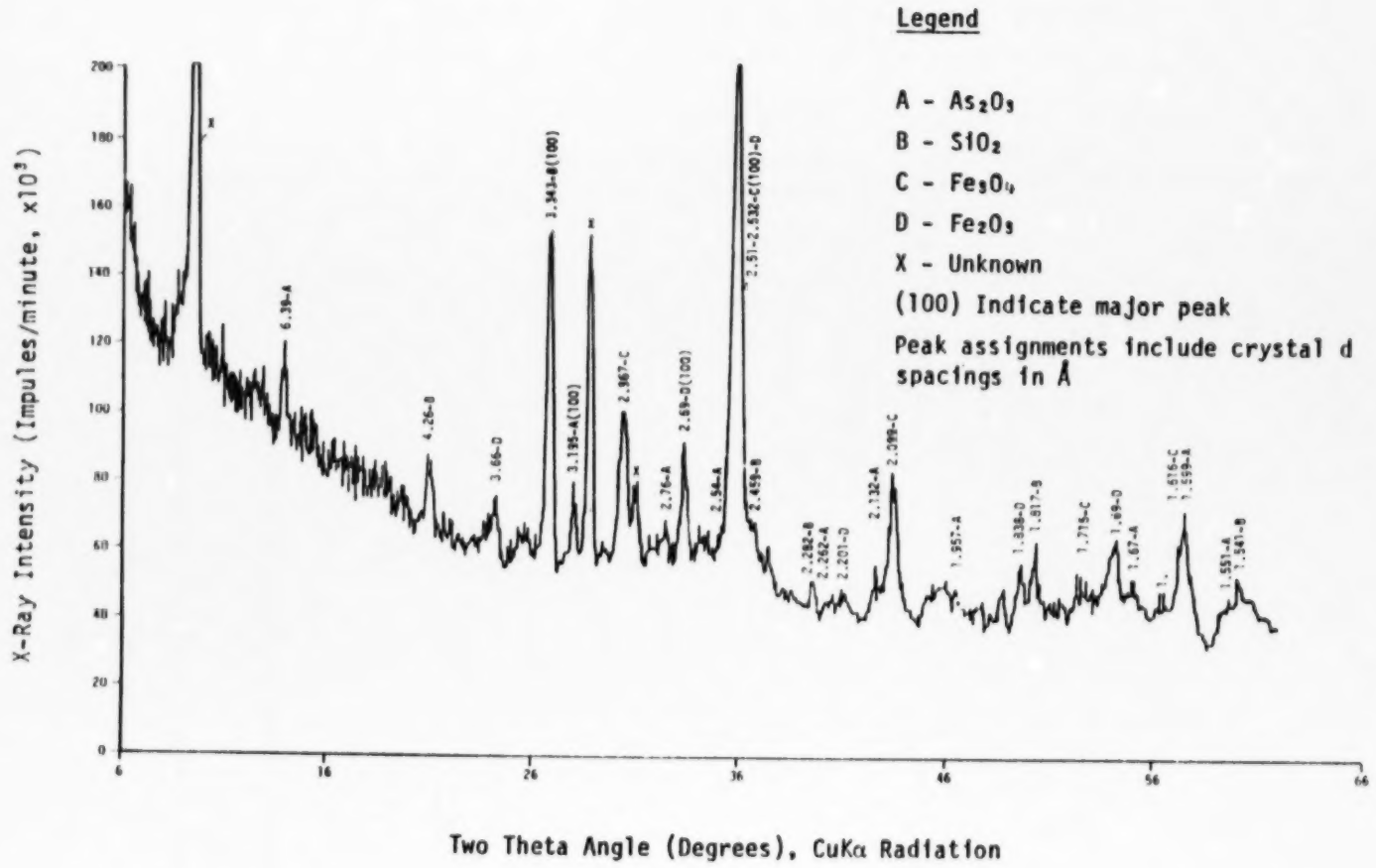

Figure 19. X-ray powder diffraction pattern for ESP solids.

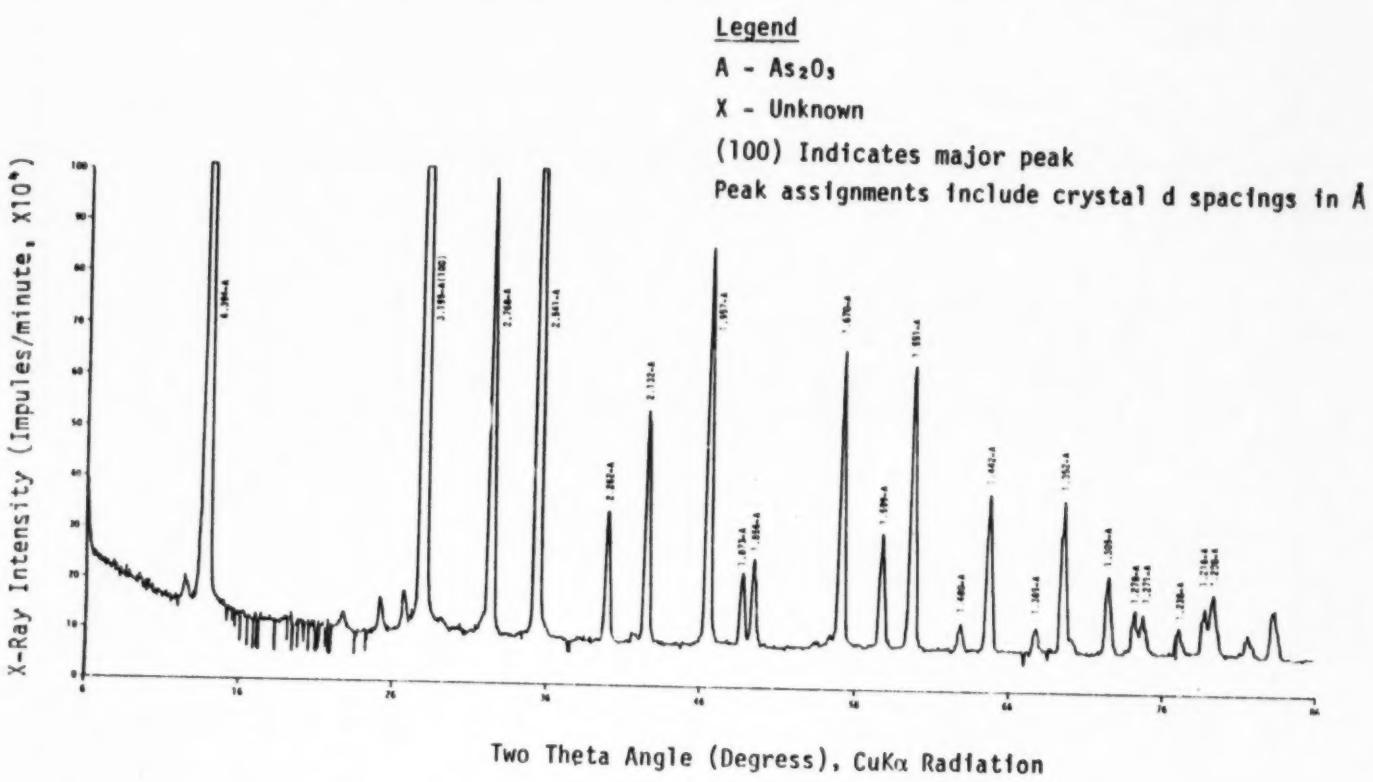
Legend
A - As_2O_3
X - Unknown
(100) Indicates major peak
Peak assignments include crystal d spacings in Å
X-Ray Intensity (Impules/minute, X10³)
Two Theta Angle (Degress), CuKα Radiation

Figure 20. X-ray powder diffraction pattern for baghouse solids.

TABLE 10. SSMS ANALYSES
(concentration in ppm weight)

	ESP Dust	Bghse. Dust		ESP Dust	Bghse. Dust
Aluminum	MC	63	Mercury	NR	NR
Antimony	MC	MC	Molybdenum	3	2
Arsenic	MC	MC	Neodymium	2	-
Barium	48	2	Nickel	MC	63
Boron	8	<1	Potassium	MC	120
Cadmium	1	<1	Rubidium	9	-
Calcium	MC	860	Scandium	5	0.2
Cerium	5	-	Selenium	55	6
Cesium	1	0.6	Silicon	MC	650
Chromium	150	9	Silver	34	6
Cobalt	520	6	Sodium	MC	54
Copper	MC	50	Strontium	36	0.8
Gallium	7	1	Tellurium	17	-
Germanium	2	0.2	Thallium	1	-
Gold	50	-	Tin	50	0.4
Iron	MC	MC	Titanium	MC	18
Lanthenum	4	-	Tungsten	30	3
Lead	460	9	Vanadium	61	19
Lithium	11	1	Yttrium	15	-
Magnesium	MC	870	Zinc	MC	120
Manganese	510	8	Zirconium	16	-

NR - Not reported

MC - Major component, >1000 ppm

SECTION 8

RESISTIVITY ANALYSES

As a part of the test program at Red Lake, voltage-current (V-I) curves were obtained for the transformer-rectifier set used on the electrostatic precipitator. A typical V-I curve is shown in Figure 21. The measurements showed no evidence of a highly resistive particulate at the hot precipitator operating at a temperature of about 380°C (720°F). This again confirms that the use of the hot precipitator to recover metal values without condensation of As_2O_3 is reliable.

We also made measurements of the resistivity of the dust at the baghouse inlet using SRI's point-to-plane probe. Data in Table 11 show that the average resistivity of the particulate entering the baghouse was 1.9×10^{13} ohm-cm at 116°C using the "spark" or plate-to-plate measurement technique. Figure 22 shows clean plate and dirty plate VI curves from the in-situ resistivity probe and clearly indicates a highly resistive particulate.

The measurements at the baghouse inlet were made so that the feasibility of using an electrostatic precipitator to control As_2O_3 emissions could be assessed using the SRI-EPA mathematical model of electrostatic precipitation[7] and data on mass loading, particle size distribution, gas temperature, electrical resistivity, and effective ion mobility.

Data from the Red Lake tests showed that conditions at the baghouse inlet were:

Mass loading - 1.2×10^4 mg/SCM (from Table 4)
Mean particle size - 1.0 micron (from Figure 8)
Gas temperature - 116°C (from Table 11)
Electrical resistivity - 1.9×10^{13} ohm-cm (from Table 11)

The particulate mass loading is fairly high, and the mass medium particle diameter of 1.0 μm reflects a very fine particulate. This combination of a fairly high mass loading and very fine particle size distribution would pose significant problems in collection by electrostatic precipitation. High currents (ion densities) would have to be achieved to effectively charge the high number density of particles. The high particulate number density could quite possibly result in the quenching of

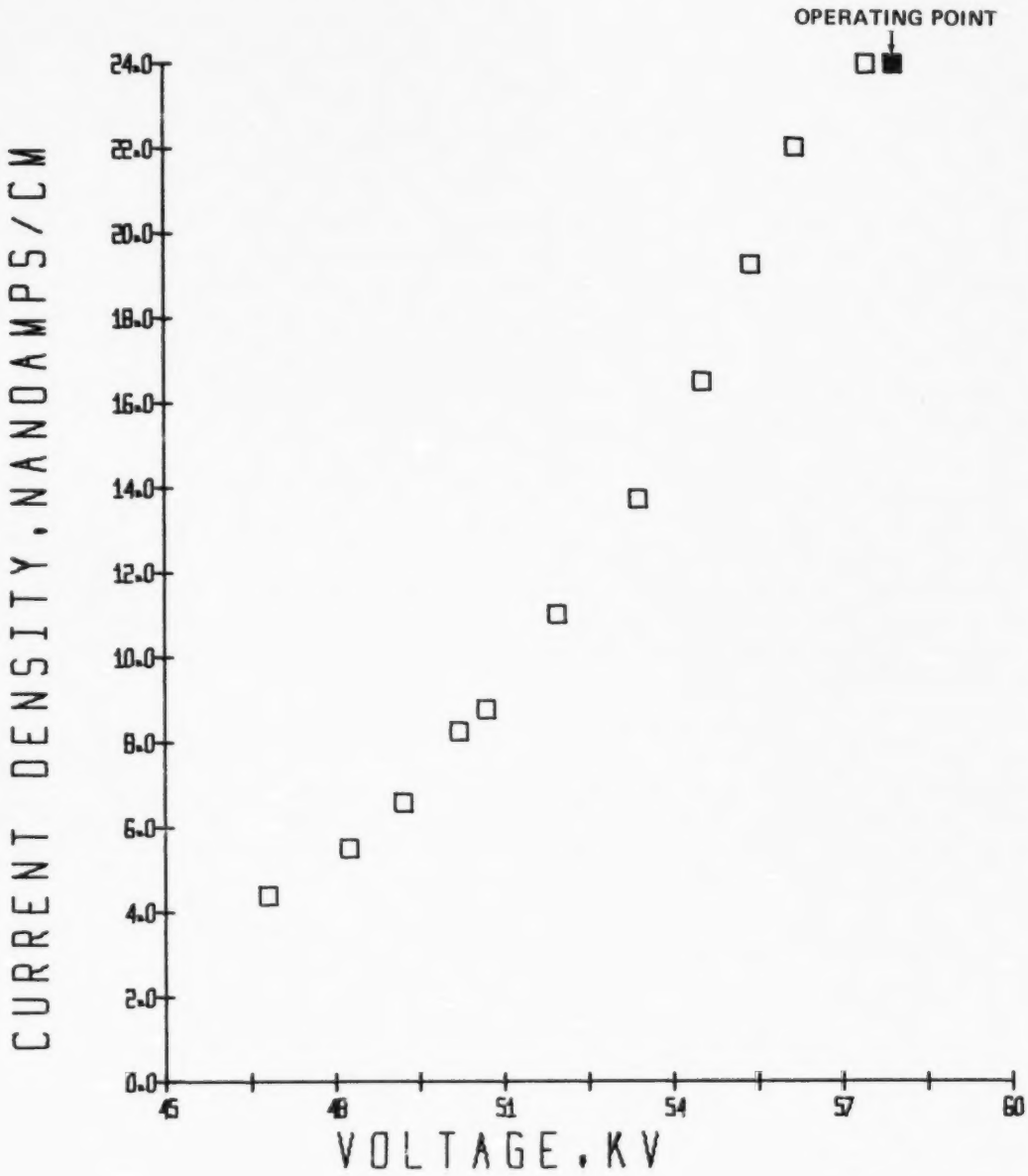

Figure 21. Typical secondary voltage-current curve.

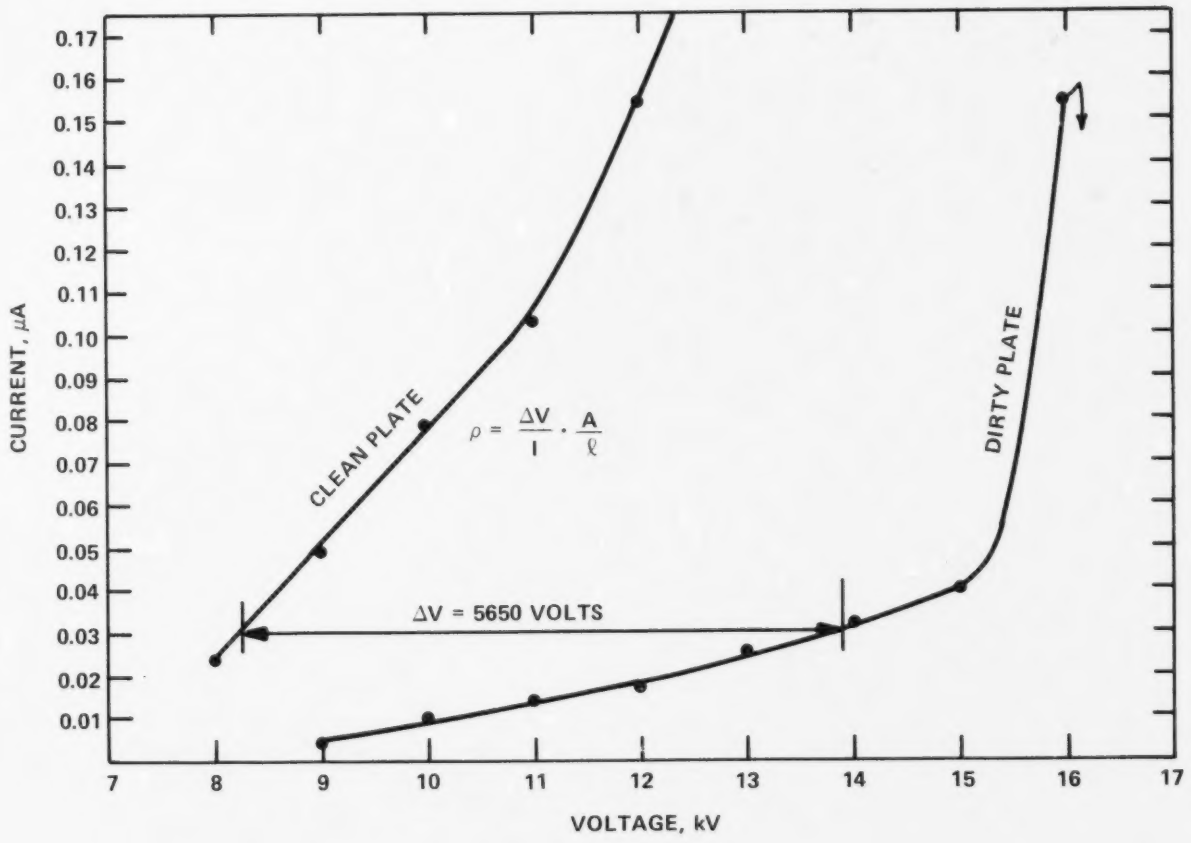

Figure 22. Clean and dirty plate voltage-current curves from in situ point-to-plane resistivity probe.

$$\rho = \frac{5650}{3.4 \times 10^{-4}} \cdot \frac{5}{.068} = 1.2 \times 10^{13} \text{ ohm-cm}$$

the corona discharge. In addition, even if a steady corona current could be maintained, sparking would occur at lower than desirable voltages due to particulate space charge effects which would result in high values of electric field in the interelectrode space.

The high electrical resistivity would also severely limit the voltages and currents which could be effectively utilized in the precipitation process. Currents would be limited to 2 nA/cm^2 or less for an assumed electrical breakdown strength of 20 kV/cm with a large susceptibility to back corona and sparking. The poor electrical conditions which would be imposed due to the high resistivity of the collected particulate would require the utilization of a very large precipitator to achieve acceptable overall mass collection efficiency.

In this application to collect As_2O_3 particles, the properties of the particulate are such as to prohibit the use of a precipitator as an effective control device unless the particulate properties can be modified. The effects due to high values of mass loading and electrical resistivity and the very fine particle size distribution would all combine to produce very poor electrical conditions which would likely be very unstable. This conclusion is consistent with results reported by Porle and Lindquist[8] who found that back corona conditions existed in electrostatic precipitators collecting As_2O_3 at 130°C unless the dust was conditioned with sulfuric acid.

TABLE 11. IN SITU RESISTIVITY - BAGHOUSE INLET

Test #	Temperature °C	°C	Cell Depth, mm	Resistivity, ohm-cm Spark	VI	E,kv/cm
1	239	115	1.24	7.69×10^{12}	6.25×10^{12}	26.6
2	241	116	2.48	2.19×10^{13}	6.49×10^{12}	30.2
3	244	118	1.00	--	1.17×10^{12}	36.0
4	241	116	0.68	1.84×10^{13}	1.40×10^{13}	52.9
5	232	111	1.34	3.11×10^{13}	1.49×10^{12}	28.0
6	241	116	1.18	1.62×10^{13}	1.16×10^{13}	35.6
Average	240	116		1.9×10^{13}	6.8×10^{12}	

SECTION 9

TECHNOLOGY TRANSFER

One of the objectives of the test program at Red Lake was to determine whether their system for recovery of metal values in a hot electrostatic precipitator, followed by quench cooling with air with collection of condensed As_2O_3 particulate in a cold baghouse, has potential for technology transfer and use for As_2O_3 control in other nonferrous applications. The test program clearly demonstrated and confirmed that the Campbell Red Lake Mines technology is effective for control of arsenic emissions from a nonferrous smelter. Modification of the system for use in other nonferrous smelters (e.g. copper smelters) appears to be technically feasible if no major difficulties are encountered in scale-up from the relatively small operation at Red Lake to a large smelting operation.

The design data for Red Lake are based on a hot-gas flow to the precipitator of about 93 SCMM (3273 SCFM) or 207 ACMM (7300 ACFM) at 370°C (700°F). After removal of low-arsenic particulate in the ESP, the gas is diluted with 302 SCMM (10,650 SCFM) ambient air in the mixer-cooler so that the gas flow to the cold baghouse is 395 SCMM (13,923 SCFM) or 518 ACMM (18,300 ACFM) at 107°C (225°F). In their case, the dilution ratio from the ESP to the baghouse was about 4.25 (i.e. on a standard basis, the gas flow through the baghouse was 4.25 times the flow through the ESP). This significant increase in gas flow is acceptable for the Red Lake installation; however, this may be a limitation in larger smelters. In any event, major considerations in potential application of this control technology to other nonferrous operations would involve design scale-up and sizing of the dilution mixer-cooler system and an economic evaluation of the baghouse system for handling the larger gas volumes that would be required in major nonferrous smelting units.

Overall, it appears that the hot ESP/mixer-cooler/cold baghouse technology may be applicable to control of arsenic emissions from systems such as copper reverberatory furnaces, electric furnaces, and converters. In some cases, such as reverberatory or electric furnaces now using hot electrostatic precipitators, control of arsenic emissions may be improved by addition of a mixer-cooler system and a cold baghouse to existing installations. Detailed heat and material balances would be

required for each particular situation; however, a preliminary evaluation of the potential applicability of the system can be made with only a limited amount of data concerning the arsenic input and distribution within the system, the gas flows and temperatures in existing (or proposed) control devices, the subsequent treatment and disposition of the gas, and the vapor pressure of As_2O_3.

For example, in primary copper smelters processing ores containing only small quantities of arsenic (e.g. less than 0.1 percent) in the feed, it is probable that the partial pressure of As_2O_3 in any process stream would be less than the vapor pressure at the exit temperature of the control device (e.g. 7×10^{-4} mmHg at 107°C). In such cases, the hot ESP/air dilution/cold baghouse system would clearly have no value. In other smelters where the process stream is sent to an acid plant, current particulate collection and scrubbing practices are generally adequate for removal of arsenic from the gas stream so that atmospheric emissions can be controlled. Also, if the process stream is to be sent to an acid plant, excessive air dilution would be undesirable so that the hot ESP/air dilution/cold baghouse control technique would not be feasible.

However, in those cases where off-gases from a smelting operation are vented to the atmosphere, the Red Lake technology for control of arsenic emissions may warrant at least a preliminary evaluation. For example, the gas flow from an electrostatic precipitator controlling particulate emissions from a copper reverberatory furnace may be about 70 m^3/sec at 315°C (150,000 ft^3/min at 600°F). Air dilution and cooling of this gas stream to 107°C (225°F) would require about 90 m^3/sec (193,000 ft^3/min) of ambient air at 25°C (77°F). The vapor pressure of As_2O_3 at 107°C can be calculated from the data of Behrens and Rosenblatt[9] as follows:

$$\log p \text{ (atm)} = - 6067/T(°K) + 9.905$$

For an As_2O_3 vapor pressure of 7×10^{-4} mmHg, the calculated emissions would be about 8 mg/SCM(5×10^{-7} lb/SCF). The emissions from the reverberatory furnace control system would then be about 3.6 Kg/hr (8 lb/hr) as As_2O_3 or 2.7 Kg/hr (6 lb/hr) as arsenic. For some copper smelters, this emission level for arsenic may be an improvement over existing systems; however, potential applicability of the hot ESP/air dilution/cold baghouse technology to any smelter operation would require a detailed evaluation and comparison with other systems such as scrubbers or spray chamber/ESP or baghouse collector combinations.

Alternatively, the use of the ESP/air dilution/cold baghouse concept may be combined with a water spray chamber to

decrease the gas loading through the baghouse or to lower the temperature attainable with a spray chamber without encountering dewpoint problems in the dust collector. These latter approaches are beyond the scope of the demonstrated control technology in use at Red Lake, however.

REFERENCES

1. Goodfellow, H. and Gellender, M., "Arsenic Poses Tricky Recovery Task," Canadian Chemical Processing, pp. 26-27, February 1978.

2. Goodfellow, H. et al, "Arsenic Removal from Roaster Off-Gases," Fourth International Clean Air Congress (1978).

3. Ensor, D.S., Hooper, R.G., and Scheck, R.W., "Determination of the Fractional Efficiency, Opacity Characteristics, Engineering and Economic Aspects of a Fabric Filter Operating on a Utility Boiler," EPRI FP-297, November 1976.

4. Perkin-Elmer, Analytical Methods for Atomic Absorption Spectrophotometry. Norwalk, CT, 1973.

5. Perkin-Elmer, Analytical Methods for Atomic Absorption Spectroscopy Using the HGA Graphite Furnace. Norwalk, CT, March 1973.

6. Dionex Corporation, Analytical Ion Chromatography, Models 10 and 14, Operation and Maintenance Manual. Palo Alto, CA, Jan. 1976.

7. Gooch, J.P., McDonald, J.R., and Oglesby, S., A Mathematical Model of Electrostatic Precipitation. Environmental Protection Technology Series, Publication No. EPA-650/2-75-037 (April 1975).

8. Porle, K. and Lindquist, B., "Electrostatic Precipitators (ESP's) in Two Stages Used for Arsenic Recovery at the Rönnskär Copper Works," Symposium Preprint Control of Particulate Emissions in the Primary Nonferrous Metals Industries (March 1979).

9. Behrens, R.G. and Rosenblatt, G.M., "Vapor Pressure and Thermodynamics of Octahedral Arsenic Trioxide (Arsenolite)", J. Chem. Thermodynamics, 4, 175-190 (1972).

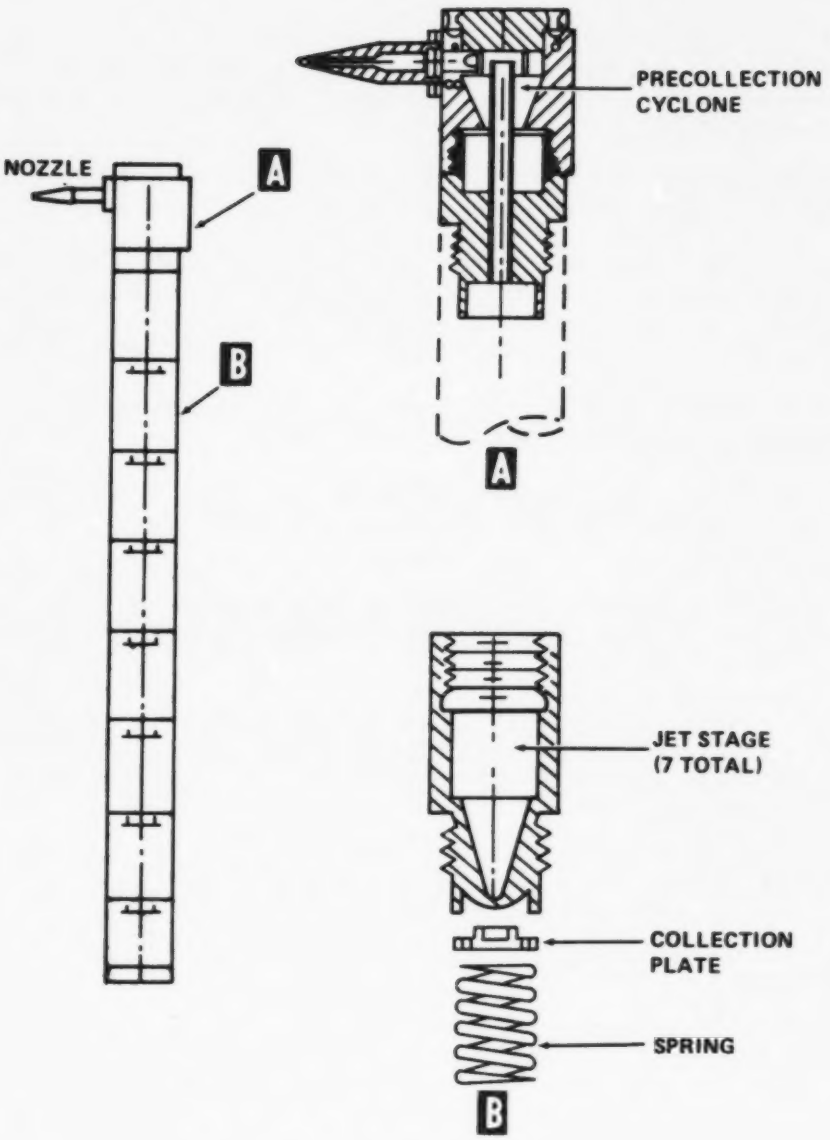

Figure A-1. Modified Brink BMS-11 cascade impactor.

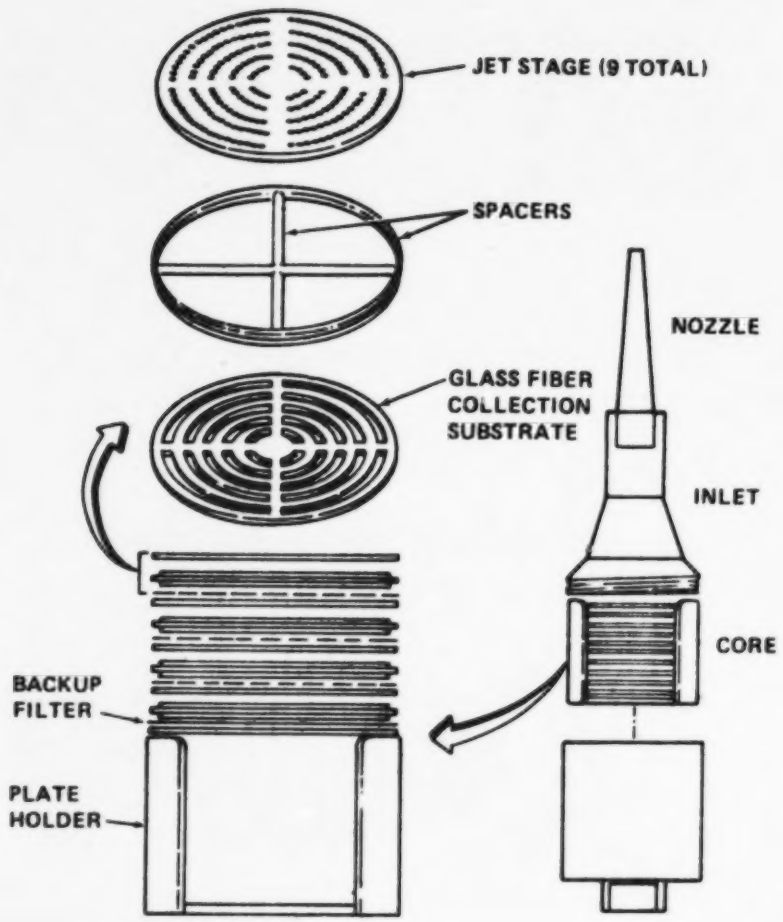

Figure A-2. Andersen Mark III cascade impactor.

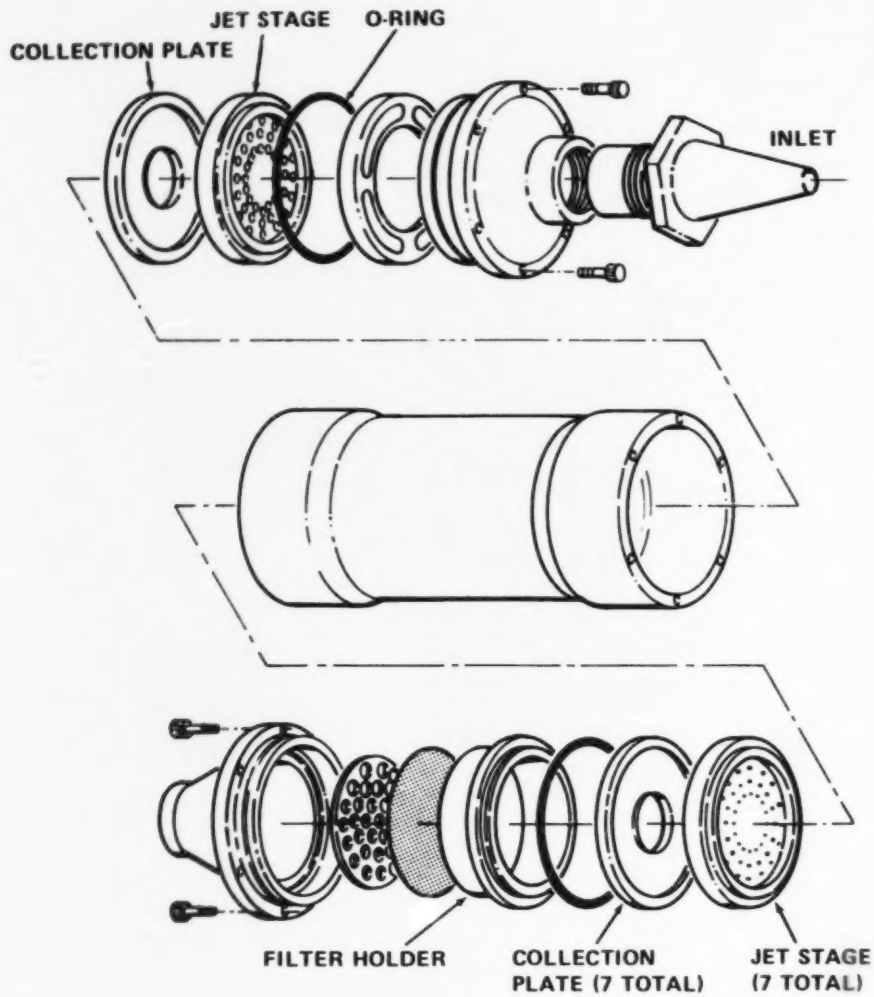

Figure A-3. University of Washington Mark III cascade impactor.

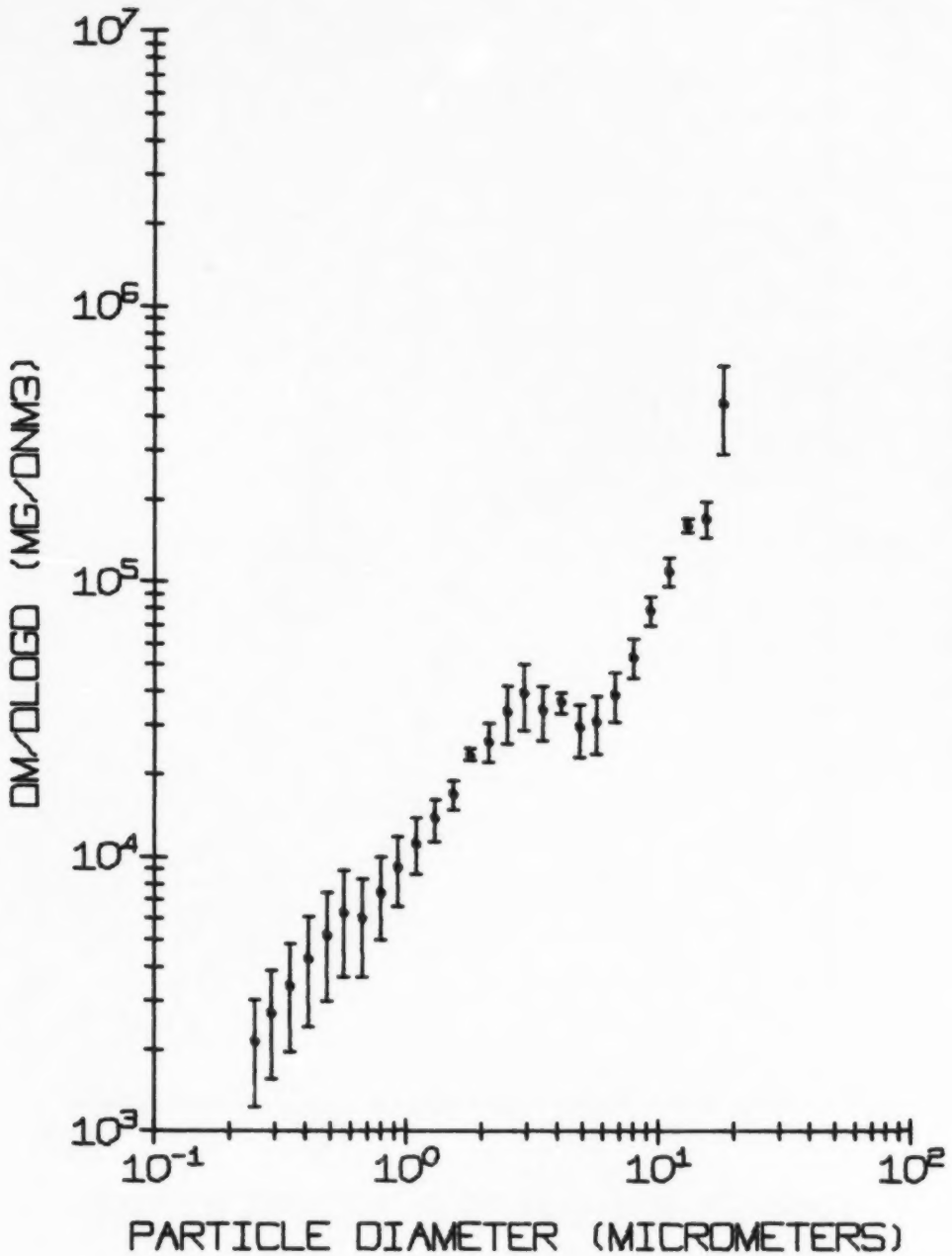

Figure A-4. DM/DlogD versus particle diameter for ESP inlet data.

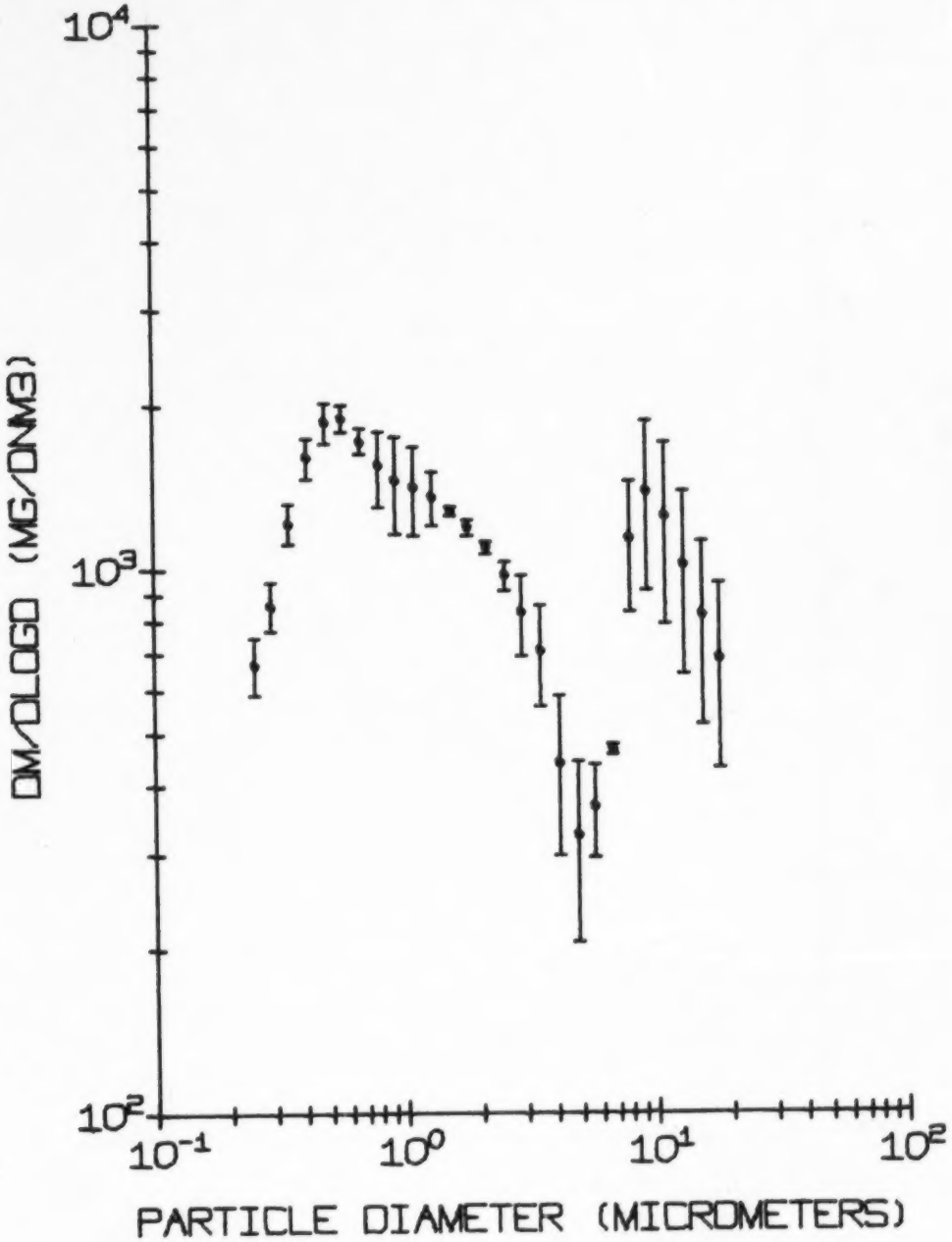

Figure A-5. DM/DlogD versus particle diameter for ESP outlet data.

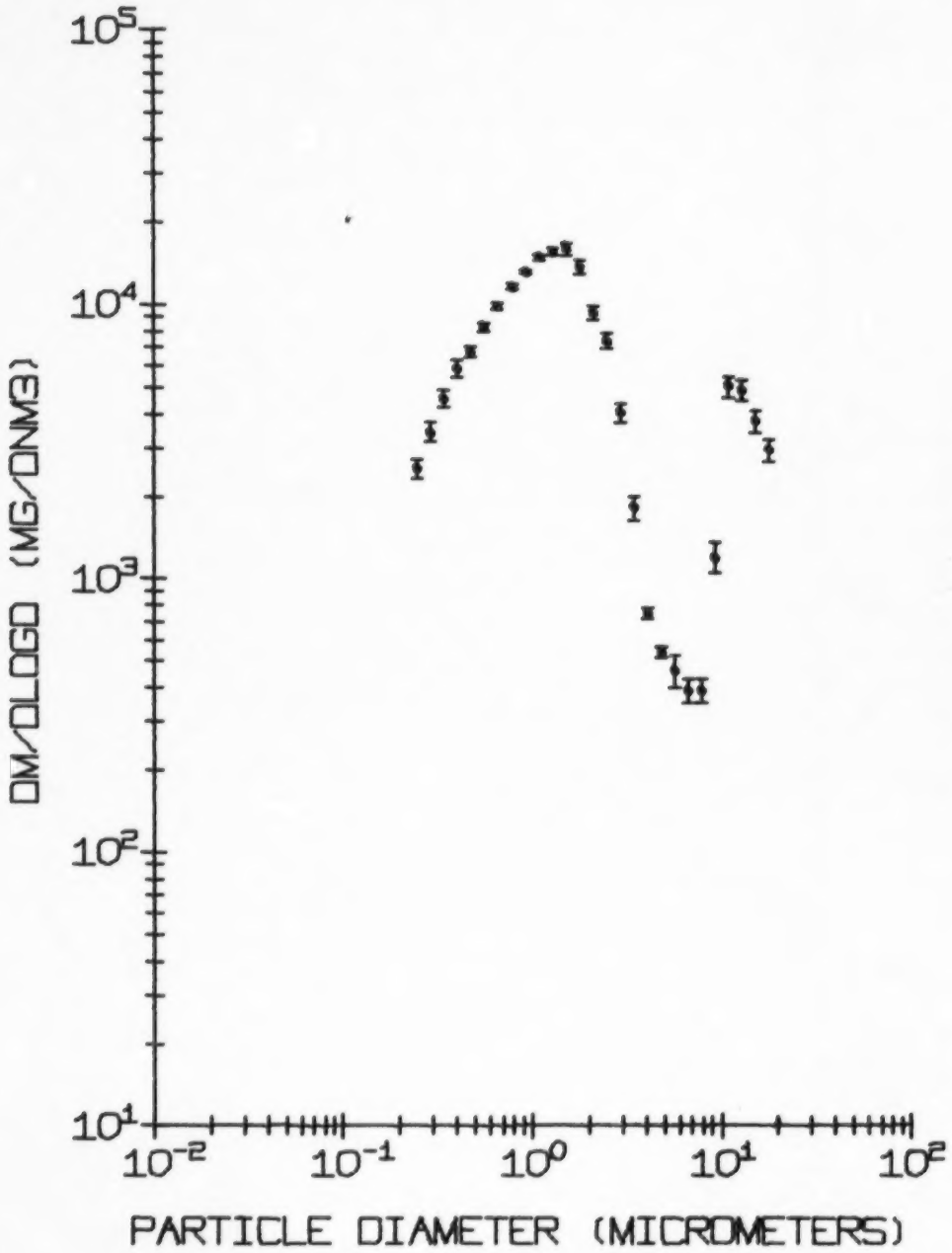

Figure A-6. DM/DlogD versus particle diameter for baghouse inlet data.

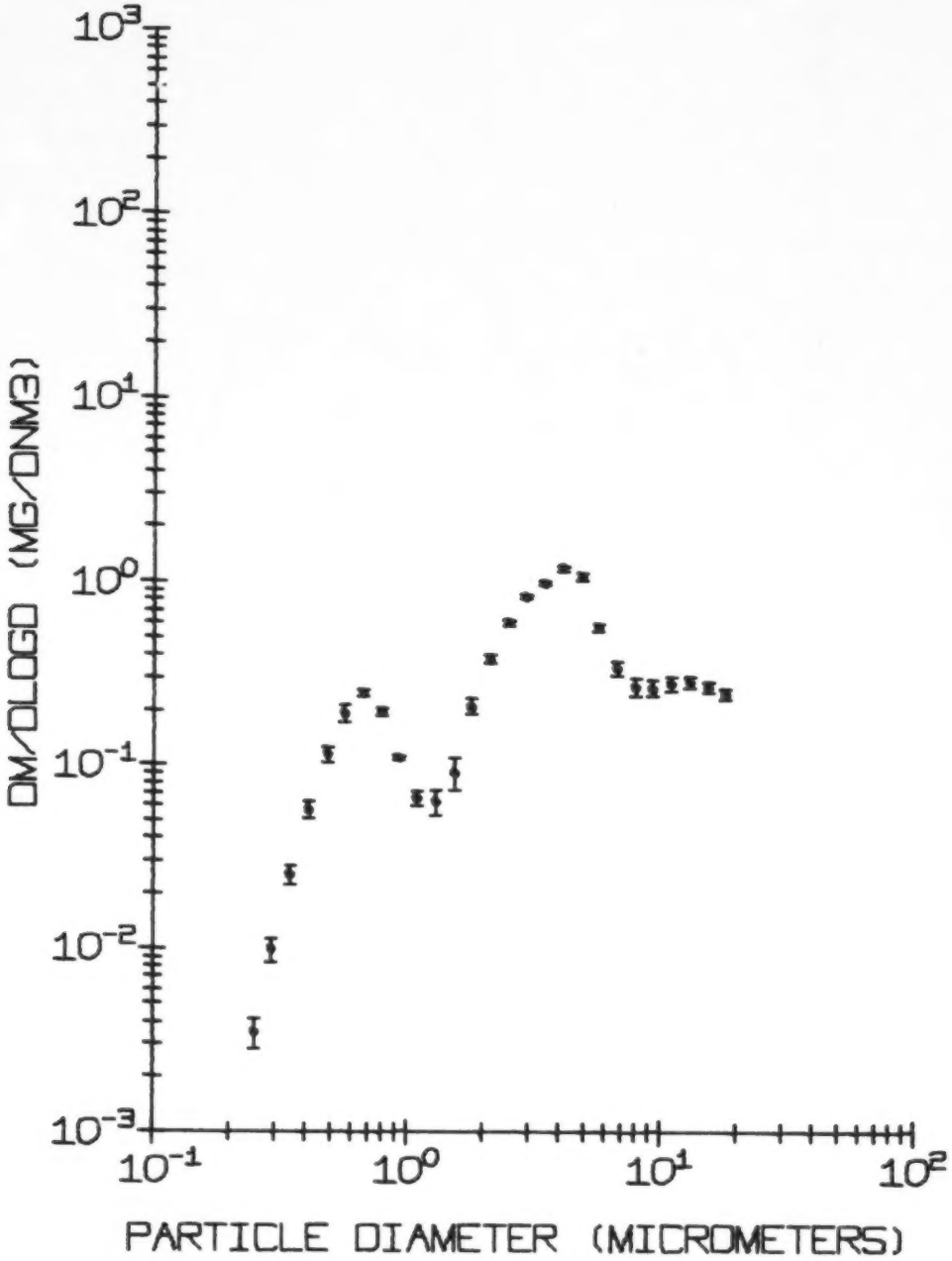

Figure A-7. DM/DlogD versus particle diameter for baghouse outlet data.